MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

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CORRIGENDA.

Vol. lxxx., p. 227, line 8 from bottom, *for* $(1 + 0 \cdot 0021\, t)$, *read* $(1 - 0 \cdot 0021\, t)$.
" lxxxiv., p. 452, line 22, *for* "1885," *read* "1886."

THE

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SESSION 1885-86.—PART III.

SECT. I.—MINUTES OF PROCEEDINGS.

9 March, 1886.

EDWARD WOODS, Vice-President,
in the Chair.

(*Paper No. 2075.*)

"On the Explosion of Homogeneous Gaseous Mixtures."

By DUGALD CLERK, F.C.S.

EXPERIMENTS were made by Hirn,[1] in 1861, to determine the pressures produced by the explosion of mixtures of inflammable gases with atmospheric air. The inflammable gases used were hydrogen and coal-gas. The vessels in which the explosions were effected were cylindrical, and comparable in capacity to the volumes existing in the Lenoir gas-engine cylinders; they were, one of a capacity of 3 litres, the other of 36 litres. The pressures produced by the explosions were much lower than was expected: hydrogen, mixed with air in the proportion of 1 volume of hydrogen to 9 volumes of air, by calculation should give a maximum pressure of 5·8 atmospheres; by experiment it was found to give only 3·25 atmospheres. Similar results were observed with other mixtures of hydrogen and air, and also of coal-gas and air.

Bunsen[2] made a more extended set of experiments in 1866, using a very small explosion-vessel of only a few cubic centimetres capacity, and passing the igniting spark through the whole length of the column to make certain of an instantaneous spread of the flame. His experiments supported those of Hirn, a precisely similar difference between the calculated and the observed pressures being proved.

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[1] "Zur Theorie der Lenoirschen Gasmaschinen." Polytechnisches Central-Blatt, Leipsic, 1861.

[2] "On the Temperature of the Flames of Carbonic Oxide and Hydrogen." By R. Bunsen, Phil. Mag. 1867, vol. xxxiv. p. 489.

By the calculated pressures they meant the pressures which would be produced by explosion, assuming the heat to be completely evolved at the moment of explosion, that is, assuming that the gases entered into complete combination at once, without reserving uncombined any portion to combine or burn afterwards, and without incurring any loss by cooling while the explosion progressed. Assuming this, and also that the specific heats of the combining gases remained unaltered at the high temperatures, they calculated the temperatures of explosion

$$T = \frac{\text{Total heat present}}{\text{Weight} \times \text{specific heat of mixture.}}$$

Thus a unit-weight of hydrogen completely burned evolves 34,170 heat-units; and 34,170 units-weight of water would be raised through 1° Centigrade; or an unit-weight of substance of the same specific heat as water, and capable of standing the high temperature, could be heated through 34,170° Centigrade. The product of the combustion is 9 units-weight of steam; if it had the same specific heat as water, the temperature produced would be $\frac{34{,}170}{9} = 3{,}800°$ Centigrade nearly; but the specific heat is only 0·370, therefore the temperature should be $\frac{34{,}170}{9 \times 0 \cdot 370} = 10{,}260°$ Centigrade. Part of the heat evolved is not available for raising the temperature, because of the latent heat of steam; correcting for this, the temperature of combustion of H and O in explosive proportions is 8,812° Centigrade nearly. Burning in air, a lower temperature is theoretically possible, because of the associated nitrogen, which may be calculated for each mixture by getting the average specific heat of the products of the explosion, multiplying by the weight, and dividing the total heat present by the product.

More recently a series of Papers has appeared[1] describing numerous experiments by Messrs. Mallard and Le Chatelier, in all of which a large difference is noticed between the calculated pressures and those actually obtained. Messrs. Berthelot and Vieille have also arrived at similar conclusions.

The experimenters all agree upon the fact of the deficit, but differ in their method of explaining it. All agree that the temperatures are much lower than should occur if all the heat were evolved, and applied to heat up the gases.

Hirn supposes the limiting cause to be the cooling effect of the

[1] "Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences," 1880–1881, Tomes 91, 93.

enclosing walls; Bunsen, the approach of the ignited gases to the dissociating point of the compounds formed by the combustion (carbon dioxide, and water); and Mallard and Le Chatelier to an enormous increase of the specific heat of oxygen, nitrogen, and the products of combustion, as the temperature increases towards 1,000° and 2,000° Centigrade.

The Author has made the experiments described in this Paper in order to obtain data requisite for the more thorough understanding of the gas-engine, and also, if possible, to arrive at some conclusion as to the relative truth of the three distinct theories.

Apparatus and Method of Experiment.—The explosion-vessel is a strong cast-iron cylinder, the internal space being 7 inches in diameter, and 8¼ inches long. It is closed completely by covers at the top and at the bottom, firmly bolted, and so arranged as to be easily and rapidly separated for cleaning the walls. Upon the upper cover is mounted a Richards' indicator, from which the ordinary reciprocating drum has been removed and a revolving one substituted, driven by a falling weight and suitable gear; a fan, moving at a high velocity, serves to render the motion uniform. The revolving drum is enamelled, and a soft black-lead pencil, held by the indicator-motion, marks upon the drum a line caused by the movement of the indicator-piston. A pair of insulated points project through a plug in the bottom-cover, and serve to ignite the mixture when a spark from a coil and battery is passed between them.

To charge the explosion-vessel, it is exhausted by an air-pump, and a measured quantity of the inflammable gas admitted from a graduated glass measuring-vessel; air is then let in, bringing the pressure up to the atmosphere again. The inflammable gas, being admitted while the vessel is almost vacuous, diffuses throughout the whole space, and the air entering afterwards, the contents are mixed thoroughly; to make perfectly sure that mixture is complete, the vessel is allowed to stand for at least half an hour before the explosion.

To check the results obtained in this manner, a mixture of gas and air in a separate gasometer was made, and introduced into the explosion-vessel by repeated exhaustion and filling; the results were precisely similar, and the first method was used in most of the experiments, being more accurate and much safer.

The explosion-vessel being charged, with the precautions common to all gas analyses for obtaining accuracy of measurement of volumes and temperatures, the drum was made to revolve at a known rate, and the spark being passed, a line was traced upon it by the

pencil ascending and descending, as the pressure rose and fell. The line shows the amount of rise of pressure, and the times of rise and fall in terms of revolutions of the drum. The tracing is precisely analogous to the indicator-diagram of an engine. It shows the pressures within the explosion-vessel from the moment of the beginning of the explosion to its completion, and after, till the pressure again becomes equal to that of the exterior atmosphere. The rising line is due to the explosion; the falling line is due to the cooling action of the cold walls upon the hot gases. The tracing is, in fact, a record of the rapidity, intensity, and duration of an explosion. Careful tracings were made, which are reproduced in Plate 1, Figs. 1, 2, and 3.

Glasgow Coal-gas and Air.—Experiments were made with explosions from five mixtures of this gas and air. Plate 1, Fig. 1, shows the curves produced. The drum made 1 revolution in 0·3 second; 2 revolutions only are shown, but the original tracings include 5 revolutions. It is unnecessary to carry the falling curve further, as in the later part the falling line is a perfectly smooth and continuous one. The time taken by the working stroke of a modern gas-engine does not exceed 0·2 second, so that it is quite enough to consider the cooling effect during 0·5 second or so, as no economical gas-engine could have a stroke so slow as to occupy 2 seconds.

In all the experiments described in this Paper, the pressure before explosion was atmospheric.

From these curves the following Table has been calculated, giving the maximum pressures and temperatures, as well as the fraction of a second elapsing between the beginning of the increase of pressure and the attainment of the maximum pressure, being the time of explosion, in different mixtures of Glasgow coal-gas and air:—

GLASGOW COAL-GAS and AIR MIXTURES.

Temperature of Gases before ignition 18° C., pressure atmospheric (14·7 lbs.).

Experiment.	Proportion of Gas by Volume.	Maximum Pressure.	Maximum Temperature. Centigrade.	Time of Explosion.
			°	Second.
a	$\frac{1}{14}$	52 lbs. per square inch above atmosphere	1,047	0·28
b	$\frac{1}{12}$	63 " " "	1,265	0·18
c	$\frac{1}{10}$	69 " " "	1,384	0·13
d	$\frac{1}{8}$	89 " " "	1,780	0·07
e	$\frac{1}{6}$	96 " " "	1,918	0·05

From these experiments it is seen that the greatest possible pressure exerted by the explosion of a mixture of Glasgow gas and air is 96 lbs. per square inch above the atmosphere; the maximum

pressure is reduced as the proportion of Glasgow gas in the mixture diminishes, and the time of explosion increases the more the mixture is diluted. With a mixture containing $\frac{1}{14}$ of its volume of coal-gas, the time of explosion is 0·28 second; with $\frac{1}{8}$ coal-gas it is reduced to 0·05 second, or from $\frac{1}{4}$ second to $\frac{1}{20}$ second. With the mixture *a*, a very large excess of oxygen is present; in mixture *e*, less oxygen is present than is required to completely burn the inflammable gas.

The times of explosion given by these experiments only apply to vessels of the same shape and capacity as used, and at the same initial temperature, 18° Centigrade. With higher initial temperatures, and vessels of different capacities and forms, the times may be very much altered.

The maximum temperatures have been calculated on the assumption of no change in volume due to chemical combination; with the most diluted mixture, the possible error so introduced does not exceed 1 per cent., and with the richest, 2 per cent.

The explosion- or rising-curves show unexpected peculiarities, which are most strongly developed in experiment *e* (Plate 1, Fig. 1). Here an actual pause occurs in the increase of temperature at a point when the temperature has risen to about 1,300° Centigrade. This will be discussed later on. In all explosions the rate of fall is slow, as compared with the rate of rise, but the difference is more striking in the richer mixtures.

Oldham Coal-gas and Air.—Many experiments were made with nine mixtures of this inflammable gas and air. The curves produced are shown by Plate 1, Fig. 2. In this case the drum revolved more slowly, so that it made 1 revolution in 0·5 second, the 2 revolutions taking 1 second.

The following Table has been calculated from the curves:—

OLDHAM COAL-GAS and AIR MIXTURES.

Average Temperature of Gases before ignition taken as 17° C., pressure atmospheric (14·7 lbs.).

Experiment.	Proportion of Gas by Volume.	Maximum Pressure.	Maximum Temperature. Centigrade.	Time of Explosion.
			°	Second.
a	$\frac{1}{15}$	40·0 lbs. per square inch above atmosphere	806	0·45
b	$\frac{1}{14}$	51·5 " " "	1,033	0·31
c	$\frac{1}{13}$	60·0 " " "	1,202	0·24
d	$\frac{1}{12}$	61·0 " " "	1,220	0·17
e	$\frac{1}{10}$	78·0 " " "	1,557	0·08
f	$\frac{1}{9}$	87·0 " " "	1,733	0·06
g	$\frac{1}{7}$	90·0 " " "	1,792	0·04
h	$\frac{1}{6}$	91·0 " " "	1,812	0·055
i	$\frac{1}{5}$	80·0 " " "	1,595	0·16

The greatest pressure produced by the explosion of a mixture of this gas and air was 91 lbs. per square inch above the atmosphere; in experiment *h* a little more gas was present than there was oxygen to burn it.

The mixture *a*, 1 volume of gas, 14 volumes of air, is the most dilute which can be ignited with the electric spark at the ordinary atmospheric temperature; a mixture containing 1 volume of gas and 15 volumes air failed to ignite, although it was repeatedly tried.

The rise of temperature in this mixture was exceedingly slow, nearly 0·5 second being taken to reach the highest temperature; as with Glasgow gas, the greater the proportion of gas, the more rapid the explosion. The most rapid in this set was in experiment *g*; the gas present by volume was $\frac{1}{7}$, the time taken being 0·05 second. With further increase in the proportion of coal-gas, the explosion becomes slower; in experiments *h* and *i* an excess of coal-gas was present.

The pause in the increase of temperature is also shown in these diagrams, but it is not so strongly marked as with Glasgow gas.

Hydrogen and Air.—Experiments were made with three mixtures of hydrogen and air; the curves produced are shown in Plate 1, Fig. 3.

The drum made 1 revolution in 0·33 second.

The following are the results:—

HYDROGEN and AIR MIXTURES.

Temperature of gases before ignition 16° C., pressure atmospheric (14·7 lbs.).

Experiment.	Proportion of Hydrogen by Volume.	Maximum Pressure.	Maximum Temperature. Centigrade. °	Time of Explosion. Second.
a	$\frac{1}{7}$	41 lbs. per sq. inch above atmosphere	826 to 909	0·15
b	$\frac{1}{5}$	68 " " "	1,358 " 1,539	0·026
c	$\frac{2}{7}$	80 " " "	1,615 " 1,929	0·01

In experiment *a*, 1 volume of hydrogen to 6 volumes of air, there is a large excess of air, and the rise of pressure upon explosion is comparatively slow, 0·15 second being required to attain the maximum pressure from the moment of the commencement. With the mixture 1 volume of hydrogen to 4 volumes of air, the explosion is more rapid, the highest pressure being attained in 0·026 second. The mixture 2 volumes of hydrogen to 5 volumes of air contains just enough oxygen to combine completely with the hydrogen; neither combining gas is in excess, and the explosion

is exceedingly rapid, taking not more than 0·01 second. With so rapid an increase of pressure, the indicator-piston is not able to move quickly enough, and accordingly considerable oscillation occurs. The first part of this diagram *c* (Plate 1, Fig. 3) has been spoiled, the piston having rushed up above the true pressure, and fallen below it for a time, until the friction brought it to rest again. With this explosion a blow was heard, as if the piston of the indicator had received a sharp stroke with a small hammer; all the other ignitions were noiseless. With hydrogen and air, the error due to molecular condensation is greater than with coal-gas and air; the temperatures accordingly have been calculated for each mixture assuming no condensation, and then assuming complete condensation. Both assumptions are untrue, and the temperature lies between the two given. It is impossible to calculate the exact temperature without knowing which of the three theories of limit is the correct one.

Practical Application of the Data obtained.—From the figures obtained the relative values of the different gases and mixtures when used in non-compression gas-engines may be calculated independently of any theoretical considerations. The function of the gas in the engine is to evolve heat, and by so doing to produce increase of pressure of the working fluid heated; it is evident that the best mixture for producing power is that in which the greatest increase of pressure is attained with the smallest relative amount of gas.

Take first the different mixtures of Glasgow coal-gas and air. Which mixture will be the most economical? In which mixture will it be most advantageous to use, say, 1 cubic inch of gas in order to obtain from that quantity of gas the greatest amount of power?

The mixtures *a*, *b*, *c*, *d*, *e*, contain respectively $\frac{1}{14}$, $\frac{1}{12}$, $\frac{1}{10}$, $\frac{1}{8}$ and $\frac{1}{6}$ of their volume of Glasgow coal-gas (Plate 1, Fig. 1); therefore 14, 12, 10, 8 and 6 cubic inches of each mixture respectively contain 1 cubic inch of gas. Suppose that the mixtures are introduced into separate cylinders, fitted with pistons of varying areas, but each within 1 inch distance from the bottom of its cylinder, then the areas of the pistons will be 14, 12, 10, 8 and 6 square inches, and each cylinder will contain just 1 cubic inch of coal-gas. As all contain equal amounts of gas, it follows that the piston upon which the greatest pressure is produced contains the mixture capable of giving the most power. The maximum pressures produced by the explosion of the mixtures are respectively, 52, 63, 69, 89 and 96 lbs. per square inch; multiply-

ing these pressures by the areas 14, 12, 10, 8 and 6, the products are 728, 756, 690, 712 and 576 lbs., being the pressures upon the different pistons, each produced by 1 cubic inch of gas, and each mixture 1 inch deep. The highest pressure is 756 lbs., and the lowest 576 lbs.; the best mixture from this point of view is therefore the one used in experiment *b*, containing $\frac{1}{12}$ of its volume of coal-gas; the worst is experiment *e*, containing $\frac{1}{6}$ of its volume of coal-gas; in the latter mixture there is an excess of coal-gas, but even taking the mixture, experiment *d*, $\frac{1}{8}$ volume of gas, when there is sufficient oxygen it only gives a pressure of 712 lbs. upon the piston. The experiments, mixtures, and pressures produced are as follow:—

	a	*b*	*c*	*d*	*e*
Proportion of gas	$\frac{1}{14}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{6}$
Relative pressure produced by 1 cubic inch of gas	728	756	690	712	576 lbs.

Taking the pressure produced by the mixture $\frac{1}{12}$ gas as 100, then that produced by the mixture containing $\frac{1}{8}$ gas is 94·1, a difference of nearly 6 per cent. in favour of the weaker mixture.

There is, however, another point to be considered before deciding which is the better mixture; the pressures in both cases may be equally good, and yet if the rate of fall of pressure is greater in the one, then that mixture may give less power, being unable to hold out long enough to be utilized by the piston of the engine. The explosion must not only give the greatest pressure for a given volume of gas, but it must be prolonged sufficiently to allow of its utilization by the piston. If it gives a good pressure which vanishes instantly, then it is useless. No explosion does this, but some explosions are more prolonged than others. Suppose the time taken by the piston in moving through the working portion of its stroke to be 0·2 second, then a comparison of the relative losses of pressure during 0·2 second from the attainment of the maximum pressure will show which is the best mixture in this respect.

Take the two mixtures having $\frac{1}{12}$ of gas, and $\frac{1}{8}$ of gas, experiments *b* and *d* (Plate 1, Fig. 1), the times of explosion are respectively 0·18 second and 0·07 second; adding to these fractions 0·2 second, the result is 0·38 second and 0·27 second, at which times the falling lines of the two curves have reached 47 lbs. per square inch, and 52 lbs. per square inch above the atmosphere. In experiment *b* the maximum pressure is 63 lbs., in *d* 89 lbs. per square inch above the atmosphere.

$$= \frac{47}{63} = 0{\cdot}75 \text{ and } \frac{52}{89} = 0{\cdot}58.$$

The pressure remaining in the one case is 75 per cent. of the maximum after 0·2 second exposure to the cooling effect of the enclosing walls; in the other case, after an exposure precisely equal in duration, it is only 58 per cent. of the maximum. The mixture containing $\frac{1}{12}$ has therefore an advantage over that containing $\frac{1}{8}$ of its volume of gas, in producing greater proportional pressure, and also in the better sustaining of the pressure when it is produced. The total advantage of the weak mixture compared with the strong one is nearly as 100 to 72.

The weak mixture is too long in attaining the maximum pressure, but in a gas-engine cylinder the slight mechanical disturbance caused by the gases flowing in at the port will cause the ignition to be sufficiently rapid.

Conclusions.—The best results with Glasgow coal-gas and air are obtained by using a mixture containing 1 volume of gas and 11 volumes of air in non-compression engines.

Examining the experiments with Oldham coal-gas, and in the same way, the following results are obtained:—

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*
Proportion of gas . . .	$\frac{1}{15}$	$\frac{1}{14}$	$\frac{1}{13}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{7}$	$\frac{1}{6}$	$\frac{1}{5}$
Relative pressure produced by 1 cubic inch of gas .	600	721	780	732	780	696	630	546	400 lbs.

Here the greatest pressure capable of being produced by 1 cubic inch of Oldham gas in a cylinder, with the piston 1 inch from the end of the cylinder, is 780 lbs., and two mixtures *c* and *e* are capable of producing it. So far as capacity to produce pressure is assumed, these mixtures, $\frac{1}{13}$ and $\frac{1}{10}$, are perfectly equal. Comparing the apparent loss of heat at 0·2 second from the point of maximum pressure, the numbers stand as follow (Plate 1, Fig. 2):—

Experiment *c*	0·24 second. 60 lbs. pressure.	0·44 second. 42 lbs. pressure.
Experiment *e*	0·08 second. 78 lbs. pressure.	0·28 second. 44 lbs. pressure.

$$c\ \frac{42}{60} = 0{\cdot}7. \qquad e\ \frac{44}{78} = 0{\cdot}56.$$

In experiment *c* the pressure remaining at 0·2 second after the maximum pressure is 70 per cent., in experiment *e* it is only 56 per cent. Here also the weak mixture is the best. The best mixture, therefore, of Oldham coal-gas and air for use in a non-compression engine, is 1 volume of gas and 12 volumes of air. The results of the examination of hydrogen and air mixtures are as follow. The experiments *a* and *b* deal with the mixtures which might be

used in a gas-engine. The mixture *c*, composed of 2 volumes of hydrogen and 5 volumes of air, ignites with a rapidity so great as to make it unsuitable for use in an engine; it would cause great shock without giving much pressure.

	a	*b*
Proportion of hydrogen	$\frac{1}{7}$	$\frac{1}{3}$
Relative pressure produced by 1 cubic inch of hydrogen	287	340 lbs.

Rate of fall—

Experiment *a*	0·15 second. 41 lbs. pressure.	0·35 second. 34 lbs. pressure.
Experiment *b*	0·226 second. 68 lbs. pressure.	0·226 second. 39 lbs. pressure.

Experiment *a* $\frac{34}{41} = 0·83$. Experiment *b* $\frac{39}{68} = 0·57$.

After being exposed to the cooling influence of the cylinder for 0·2 second from the time of maximum pressure in experiment *a*, 83 per cent. of the pressure remains; but in experiment *b* only 57 per cent.; this makes the weaker mixture the better of the two, notwithstanding that a higher proportional pressure is produced in the stronger one.

Comparing Glasgow gas, Oldham gas, and pure hydrogen, the two samples of gas are very nearly equal in capacity for producing power, equal volumes of the gases developing in their best mixtures, Glasgow 758 lbs. pressure, and Oldham 780 lbs. pressure; the former, however, gives a more sustained pressure in 0·2 second after the maximum pressure, 75 per cent. of the pressure still remaining, the latter 70 per cent. Glasgow gas will therefore give greater power for a given consumption of gas than Oldham. Hydrogen is not at all a good gas to use, the best mixture only producing a maximum pressure of 287 lbs., with 83 per cent. remaining after 0·2 second.

The difference is so great, that an engine capable of indicating 10 HP. when using Glasgow or Hollinwood coal-gas, will not indicate more than 3·7 HP. using hydrogen gas. If more hydrogen were put into it to get up greater power, very great waste of heat would be occasioned.

The Three Theories of the Cause of Limited Pressure, Cooling, Dissociation and Increase of Specific Heat.

In all the experiments made by the Author, the observed pressure falls far short of that calculated from the amount of heat present as inflammable gas. A recent analysis of Manchester coal-gas, which is very similar to that under experiment, shows that

1 lb. completely burned evolves enough heat to raise 12,200 lbs. of water through 1° Centigrade. The heat of combustion is 12,200 Centigrade heat-units.

Taking the average specific heat of the mixed gases CO_2, H_2O and N and O remaining after combustion as 0·200, the temperatures which should have been attained by the combustion of the different mixtures of Oldham coal-gas and air have been calculated.

OLDHAM COAL-GAS and AIR.

Experiment.	Proportion of Gas.	Observed Maximum Temperatures. Centigrade. °	Calculated Maximum Temperatures if all heat evolved. Centigrade. °	Percentage of Heat accounted for by Maximum.
a	$\frac{1}{15}$	806	1,786	44·6
b	$\frac{1}{14}$	1,033	1,912	53·6
c	$\frac{1}{13}$	1,202	2,058	58·0
d	$\frac{1}{12}$	1,220	2,228	54·4
e	$\frac{1}{10}$	1,557	2,670	58·0
f	$\frac{1}{8}$	1,733	3,334	51·7
g	$\frac{1}{7}$	1,792	3,808	46·8
h	$\frac{1}{6}$	1,812	..	..
i	$\frac{1}{5}$	1,595	..	..

The mixtures *h* and *i* have not been calculated, as an excess of gas is present. In the most favourable experiment only 58 per cent. of the heat known to be present is accounted for by the increase in temperature; in some manner 42 per cent. of the heat is suppressed and prevented from causing further increase of pressure. The loss by cooling previous to the maximum pressure accounts for a portion of the heat, especially in the weaker mixtures where a considerable time elapses between the beginning of the increase of pressure and the maximum pressure. An estimate of this loss is made by measuring the fall of pressure after the maximum pressure, during the same time as is taken to get the maximum pressure.

This increases the amount of heat accounted for; the totals are

	a	*b*	*c*	*d*	*e*	*f*	*g*
Per cent.	64·6	70·7	77	68	70	62	..

There is still a deficiency, ranging from 23 per cent. to 38 per cent.

The hydrogen curves also show the same phenomenon.

Experiments	*a*	*b*	*c*
Heat of combustion of hydrogen present . . .	100	100	100
Heat accounted for by maximum temperature and loss previous to its attainment	55	70	54

The heat remaining to be accounted for being 45 per cent. and

30 per cent. Whatever the explanation of this phenomenon in homogeneous explosive mixtures, whether poor or rich in gas, its existence cannot be denied.

Theory of Limit by Cooling.—This is Hirn's theory, as already stated. It supposes that when the explosion occurs, a point is reached when the cooling effect of the enclosing walls is so great that heat is abstracted more rapidly than it is evolved by the explosion, and accordingly the pressure ceases to increase, and begins to fall. The maximum pressure falls short of what it would be if no heat were lost during the progress of the explosion to the walls. Mr. Witz has revived this theory, and has supported it by a number of interesting experiments, which, however, do not appear to the Author to warrant his conclusions. If it be true that the cold surface of the vessel is the limiting cause, then the maximum pressure produced in exploding the same gaseous mixture in vessels of different capacity will greatly vary. When the vessel is small, and the surface therefore relatively large, more heat should be abstracted and lower pressures should be produced. This is not the case. The maximum pressure produced by an explosion is almost independent of the capacity of the vessel. The close agreement between the experiments of Bunsen and those of Berthelot, conducted with very dissimilar vessels, and the slight difference of pressures produced in vessels of 300 and 4,000 c.c. capacity by Berthelot, show that surfaçe is but a small factor in the problem. The Author's experiments confirm this conclusion. Surface does not control the maximum pressure, although it causes a more rapid fall after the maximum has been attained.

Theory of Limit by Dissociation.—This is Bunsen's theory, and is undoubtedly very largely true. The fact that no unlimited temperature can be attained by combustion, even when the use of non-conducting materials prevents cooling almost completely, is so conclusively established by science and practice, that gradual combination may be safely taken as occurring, to a considerable extent, at the higher temperatures used in gas-engines, and attained in the explosion of gaseous mixtures. But there is a difficulty in its application to all cases. In experiment *a* (Plate 1, Fig. 2), with Oldham gas and air, when the maximum temperature is 806° Centigrade, the apparent loss of heat is 65 per cent.; with experiment *f*, maximum temperature 1,733° Centigrade, the apparent evolution of heat is 62 per cent., practically identical results. This is also true of hydrogen mixtures (Plate 1, Fig. 3):—

Experiment *a*, max. temp. 900° Centigrade, apparent evolution of heat 55 per cent.
" " 1,700 " " " 54 "

If dissociation entirely explained the limit, then as the water and carbonic acid must be dissociated more at the higher than at the lower temperature, the deficiency should be greater at 1,700° Centigrade than at 900°. It is not so. Some other cause than dissociation must therefore be acting to check the increase so powerfully at the lower temperature; the amount of dissociation cannot be nearly one-half at 900° Centigrade. The problem is more complex than has been hitherto supposed.

Theory of Limit by the Increasing Specific Heat of the Heated Gases.—Messrs. Mallard and Le Chatelier have advanced the theory that up to temperatures of about 1,800° Centigrade dissociation does not act at all, or only to a trifling extent. They consider that the gases are completely combined or burned at the maximum temperature of the explosion. All the hydrogen or carbon is combined with oxygen, to form steam and carbonic acid. But the specific heat of nitrogen, oxygen, and the products of combustion increases with increasing temperature, becoming nearly doubled when approaching 2,000° Centigrade. The apparent limit is due, not to the suppression of combustion, as required by the dissociation theory, nor to loss of heat by the cooling theory, but to the absorption of the heat, which is completely evolved, by the increasing capacity for heat of the exploded gases. The same objection applies to this as to dissociation. If it were entirely true that specific heat increased with increasing temperature, a greater proportion of heat would apparently be evolved at the lower temperatures, which is not always the case. To calculate specific heat in this way, it is necessary that combustion must be completed at the maximum temperature; but the curves prove that combustion is not completed at the maximum temperature, as may be noticed in the hydrogen curves (Plate 1, Fig. 3). The weakest mixture, experiment *a*, explodes slowly, taking 0·15 second to reach the maximum pressure; but when the maximum pressure has been reached, it does not begin to fall at once. For nearly 0·10 second it remains constant, as if no cooling whatever were going on. But it is known that the gases are losing heat, and it follows that heat is being evolved at precisely the same rate as it is being lost. To say, then, that the deficiency of pressure in this case is due to change in the specific heat is plainly wrong; it is manifest that if heat is being evolved, keeping up a constant temperature, then combustion is still going on. The falling curves prove the same thing. If, from the period of intersection, the curves *c* and *b* fall at different rates, as is seen in Plate 1, Fig. 3, then they cannot be simply volumes of heated air cooling. Falling from the same

point of temperature and pressure, if no heat were added, the lines should coincide; but *c* lies above *b*, so that it is receiving heat if *b* is receiving none, or receiving a greater quantity if *b* is receiving any. The same volume of a gas, at the same temperature and pressure, will always cool at the same rate. The theory of change of specific heat is therefore untenable, because it supposes combustion to be invariably complete at the maximum temperature, when the experimental curves show that it is still proceeding.

In the Author's opinion none of the theories affords a complete explanation. The cooling action of the walls of the cylinder upon the intensely hot gases cannot have imposed the sole limit upon increase of pressure, or the loss during rise of pressure would be sufficient to make up the deficiency; it is not nearly enough, even with the weakest mixtures when the time of cooling is longest.

Again, dissociation cannot be the sole limiting cause, as that would necessitate the richest mixtures invariably showing the greatest deficiency; in the case of hydrogen and air, the most dilute mixture, experiment *a*, and the strongest mixture, experiment *c*, show respectively 55 and 54 per cent. of the heat as accounted for. With Oldham gas and air also the weak mixture, experiment *a*, and the strong mixture, experiment *f*, show nearly equal amounts of heat accounted for, namely 64·6 per cent. and 62 per cent. The mixtures of intermediate composition always give explosions in which the largest percentage of heat is accounted for, proving thereby that more than one limiting cause operates.

With dissociation as the sole limiting cause, higher temperatures, more dissociation and therefore less complete combustion, lower temperatures, less dissociation and therefore more complete combustion, dissociation undoubtedly acts at the higher temperatures, but probably along with other limiting causes.

In view of these results, the Author considers the theory of change in the specific heat of the gases as untenable; the deficiency of pressure is as great at 806° Centigrade as it is at 1,792° Centigrade, and at intermediate temperatures it is not so considerable. If the specific heat of N, O, and of the products of combustion, increases sufficiently at 806° to account for the deficiency, then there must be a decrease of specific heat between 806° Centigrade, and 1,557° Centigrade, and a further increase between the latter temperature and 1,792°. Such changes are highly improbable, and it is unnecessary to suppose any change in specific heat to explain the facts completely.

FULLER ACCOUNT OF THE PHENOMENA DURING EXPLOSION.

In the Author's opinion no single cause explains the limit and other phenomena of gaseous explosion. The actions in operation are more complex than have been generally supposed. To him it seems that much confusion has arisen through the neglect of properly distinguishing between two distinct and separate phenomena which occur during explosion. These are inflammation and combustion. Inflammation is the progressive communication of a flame, originated at one or more points in any explosive mixture, to the uninflamed portion. When the whole space is filled with flame then the inflammation is complete. Combustion is the burning or combination of the inflammable gases with the oxygen present; it is not completed until after the hydrogen has combined with oxygen to form steam, and all the carbon has combined with oxygen to form carbonic acid. If from any cause part of the hydrogen or carbon at a given moment still exists in the free state, while there is oxygen to burn it, the combustion is incomplete.

Study first the process of inflammation. The experiment *e* (Glasgow gas, Plate 1, Fig. 1) shows a peculiar rising curve. The flame lit at one point in the cylinder at first spreads slowly, and then with great acceleration. At the point marked 1 upon the explosive curve, the pressure just begins to rise above that of the atmosphere; at the point 2, the pressure has become 20 lbs. per square inch; at the point 3, 40 lbs.; and at the point 4 it has become 60 lbs., being equal increments of pressure. To increase from the atmosphere to 20 lbs. per square inch above it takes 0·02 second; from point 2 to 3, takes 0·006 second; and from 3 to 4 it occupies 0·004 second. These times are proportional to 1, 0·3, 0·2, that is, the increase of 20 lbs. between points 3 and 4 takes place in one-fifth of the time occupied by the first 20 lbs. between the points 1 and 2. At the point 4 the rate suddenly changes, rising for only 5 lbs. more, and then falling during nearly 0·01 second. The pressure then rises again, but never at so rapid a rate as in the earlier portion of the curve. At first the Author was inclined to attribute the extraordinary check in the figures of the explosion to some defect in the indicator, but the weaker mixtures with slower explosions, *d*, *c*, *b*, exhibit similar pauses at the points 4, 4, 4, and even *a*, the slowest of all, shows a change in the nature of the curve as it approaches the maximum. The Oldham gas curves (Plate 1, Fig. 2) indicate precisely similar

phenomena. The hydrogen curves (Plate 1, Fig. 3) show no such check. It may be taken as proved that the pause actually exists, and is not due to any defect of the indicator.

With both the Otto and the Clerk engines similar explosive curves are obtained. It is hardly conceivable that so marked a check upon the explosion could take place while the process of inflammation was still proceeding; the flame once started necessarily spreads throughout the whole volume of a closed vessel with ever-increasing rapidity. With any inflammable mixture it is not a case of uniform rate of progression, but of a rapidly accelerating one. Mr. Mallard's experiments clearly prove this. The rate of propagation of the flame backwards in a tube open at one end to the atmosphere, and containing a similar mixture of coal-gas and air to that used in experiment *a*, is 1·01 metre per second.

Mr. Mallard states that in a closed vessel the rate is at least ten times that amount; as the Author's explosion-vessel is 8 inches long, the flame would completely fill it in 0·02 second. It may be considered certain that in 0·03 second the vessel is filled with flame in every part. Why then does the pressure again increase after pausing on the explosion curve? If it is filled with flame why is the maximum temperature not attained? The Author will suggest what he considers a sufficient explanation. In an ordinary fire-grate, a flame communicated to the coal at one point gradually spreads till the whole is incandescent; the solid coal may be every part of it burning, and yet a further accession of air will cause it to glow more brightly, that is, it increases in temperature. It does not follow that because every part of the fuel in the grate is incandescent it is completely burned; complete inflammation here plainly does not mean complete combustion. Explosions have often occurred in flour-mills and in coal-mines from the diffusion, throughout the atmosphere, of minute combustible particles of flour or of coal-dust. If the inflammable dust is present in suitable quantity, a flame applied at one part will cause an explosion, the flame spreading from dust-particle to dust-particle with great rapidity. Suppose a certain confined volume to be completely inflamed, it by no means follows that pressure then ceases to increase; all the little particles of flour or coal may be aglow, but may increase in temperature subsequent to complete inflammation. Even if they do not increase in temperature after complete inflammation, they may still burn till completely consumed at too slow a rate to cause increasing pressure; pressure may even fall and the burning continue.

Gaseous explosions behave in precisely this way. The flame

fills the vessel with great rapidity, but the subsequent burning may be continued; all the inflammable gas-particles and the air may be at a very high temperature, completely inflamed, in fact; and yet the combustion be incomplete, and it may depend altogether upon the nature of the mixture whether further increase in temperature occurs. In experiment *e* (Plate 1, Fig. 1) the flame has filled the whole vessel before the point 4 is attained; the hydrogen gas, however, has burned first, and a check occurs until the temperature attained, nearly 1,200° Centigrade, decomposes the hydrocarbon; the hydrogen thus liberated burns, and with it the carbon, raising the temperature further. The checks to rapid combustion now come more into play; the temperature is nearly 2,000° Centigrade, combustion still proceeds, but too slowly to prevent a fall of temperature by the cooling action of the walls of the vessel.

In many chemical combinations it has been proved by Messrs. Vernon-Harcourt and Esson, and Professor E. J. Mills, and Dr. Gladstone, that the rate at which the reaction proceeds depends upon the proportions existing between the masses of the acting substances present and those neutral to the reaction, and that combination proceeds more slowly as dilution increases. From this it follows, that in a combination where no diluent is present, the first part of the action is more rapid than the last; at first all the molecules in contact are active; but, after some combination has occurred, the product formed acts as a diluent, preventing contact so frequently as would otherwise occur. The last portion of the reaction having to go on in the presence of the greatest dilution is comparatively slow.

The actions investigated by these chemists are, in Dr. Gladstone's experiments, the action of potassic sulphocyanide upon ferric chloride, hydrochloric acid upon cupric sulphate, etc., in various states of aqueous dilution; in Messrs. Vernon-Harcourt and Esson's experiments, hydric dioxide upon hydric iodide, also in aqueous solution. The Author's experiments prove that the generalizations arrived at by these chemists, for the very slow chemical actions investigated by them at low temperatures, hold equally good in the case of the rapid chemical combinations occurring at high temperatures producing explosion. In a rich mixture, where the acting gases are but little diluted by neutral gas, the combustion is at first exceedingly rapid, but becomes slower as it proceeds, because of the diluting effect of the products. In a poor mixture, when the molecules of the acting gases are widely separated by diluent, the combustion is slow from the first. The inflammation of both rich and poor mixtures may be made indefinitely rapid by suitable

means, such as mechanical disturbances, or applying flame at many points simultaneously, but this will have little effect upon the maximum pressures. They will remain nearly constant.

Berthelot's experiments upon the explosive-wave illustrate the effect of rapid ignition of a considerable portion at once, and the almost instantaneous explosion of the whole mass, but they do not hasten the general combustion.

In all gaseous explosions the attainment of the maximum pressure may be made indefinitely rapid, but its intensity will not be increased, except in cases of extreme dilution, when heat may be lost during inflammation.

When inflammation is nearly instantaneous, as it is in most gas-engines, and as it was in many of the Author's experiments, the maximum temperature does not coincide with the complete combustion of the gases; this is because the rate of combustion after complete inflammation becomes less and less as the combustion proceeds, on account of the diluting effect of the products; the cooling effect of the enclosing walls, which is not powerful enough to prevent increase during the progress of inflammation and the first part of the combustion, gradually overpowers the rate of the addition of heat, and then fall occurs, which, however, may be very slow.

Dissociation acts most powerfully at the higher temperatures, and diminished rate of combination at the lower temperatures, the first result being that not more than one-half the heat is evolved during an explosion at the maximum temperature, whether it be 2,000° Centigrade or as low as 800° Centigrade. All the curves show this continued combustion; it is noticeable that wherever the falling line from a high-temperature explosion crosses that from a low-temperature one, the latter remains the higher during the rest of the fall, that is, it cools more slowly, or rather, more heat is being added to keep up the temperature.

The filling of the whole space with flame does not mean that the combustion is complete; the pressure may continue to rise for a considerable time afterwards. It certainly is so in experiments *c*, *d*, *e* (Plate 1, Fig. 1), and in experiments *e*, *f*, *g*, *h*, *i* (Plate 1, Fig. 2).

In the case of the more dilute mixtures it is apparent that after the inflammation of the whole mass combustion still goes on, and that it becomes slower as the temperature increases. This is evident in experiments *a* and *b* (Plate 1, Fig. 1), and *a*, *b*, *c* (Plate 1, Fig. 2).

In these experiments, as the maximum temperature is approached,

the cooling effect of the cylinder-walls increases, at the same time combustion becomes more and more difficult and slow, the two opposing forces balance each other for a short time, combustion proceeding at a rate just sufficient to make good the loss by cooling. The cooling slowly overcomes combustion, and a slow fall of pressure occurs; the more dilute the mixture used the slower is the fall and the longer is the combination continued into the falling curve. The fact that the falling lines obtained by the explosion of the weaker mixtures often cross the falling lines from the stronger mixtures shows that combustion is going on, and that the weaker explosion is apparently cooling more slowly, that is, burning is going on while the stronger explosion is more spent and the residual gases are simply cooling.

Conclusions.

1. Messrs. Mallard and Le Chatelier's theory of increased specific heat of the gases, nitrogen, and oxygen at high temperatures, is, in the Author's opinion, erroneous.

2. Dissociation probably occurs at the higher temperatures to a considerable extent, but it is not the sole cause imposing a limit to the pressure.

3. Combustion is very similar to other chemical actions, the first part of the reaction occurring rapidly, and proceeding with increasing difficulty as the combination approaches completion.

4. The explosion-vessel is entirely filled with flame before the combustion is complete. The spread of the flame and the combustion of the gases are distinct phenomena.

5. The limiting causes act after the flame has spread completely.

6. The limiting causes in weak mixtures are diminution in the rate of burning as the reaction approaches completion, and consequent limiting by the rate of cooling. The combustion may cause the evolution of heat at rates greater than, equal to, and less than, the rate of cooling.

The Paper is accompanied by several tracings, from which Plate 1 has been engraved.

[Discussion.

Discussion.

Mr. Imray. Mr. JOHN IMRAY said that he did not consider the Paper a practical one. It was very interesting, scientifically, but seeing that it was held forth as giving some information which might be a help in relation to gas-motor engines, he thought that there it particularly failed. The experiments conducted by the Author seemed to have been carefully and purposely conducted in such a way as to have all the conditions absent that were presented in the gas-motor. In the first place, the Author took pains to put into the vessel a homogeneous mixture, but he knew that in no gas-engine, including his own, was there anything like a homogeneous mixture in the cylinder at the time of explosion. Another thing which the Author had carefully abstained from doing was to have in the cylinder, besides the explosive mixture, something in the shape of an inert fluid which would utilize the heat produced by the combustion. In the Author's engine a large volume of inert fluid was present at the time of combustion, but that condition was quite absent in these experiments. Another condition which was absent was this: in a gas-motor engine it was not merely the combustion and rise of pressure in a space of constant size that took place, but it was combustion in a continually expanding space, and all the conditions of cooling and loss of pressure were totally different in an expanding space from what they were in a constant and confined space. He ought to add that when the piston was moving forward in the cylinder there was always an additional surface exposed for cooling, and that was absent in the Author's experiments. Considering that all these conditions, which were essentially necessary conditions of a gas-motor engine, were absent, he failed to see what these experiments taught. They might afford something to talk about, but their results were utterly unpractical. He thought the purpose of Papers read at the Institution should be to study conditions occurring in actual practice, and to see what could be learnt from them. He was very sorry to have to use such hard criticisms upon an interesting Paper, but he had learnt nothing from it.

Dr. Hopkinson. Dr. JOHN HOPKINSON had not much to remark upon the Paper itself, but the last speaker had given some subject-matter for reply. He might therefore say something more than he should have done if those remarks had not been addressed to the Institution. Mr. Imray contended that this was not a practical Paper. In a new application of science it appeared to him that the most

Dr. Hopkinson.

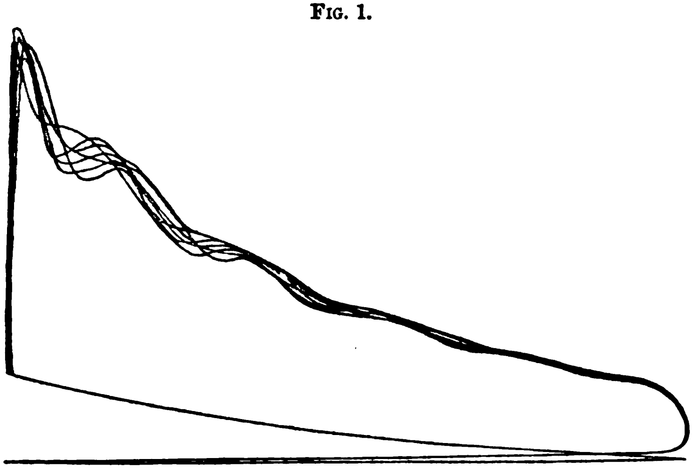
practical way of attacking a subject was to analyze it to a certain extent, to make arrangements in which a portion of the conditions were present and others were absent, and to see what were the effects. That was what the Author had done. Mr. Imray truly said that in an actual gas-engine expansion would be going on, and that if gas-engines were to do work they must inevitably have expansion going on. That was perfectly true. It was not very difficult to allow for the cooling caused by that expansion, but the Author had done better; instead of experimenting with a gas-engine and correcting the observations, he had obtained conditions in which that expansion would not exist, and had investigated the results which were obtained when expansion was absent. Having ascertained the laws of the simple case, deductions could safely be made as to what happened in more complicated conditions. That appeared to him to be not only a thoroughly scientific way of attacking the subject, but one which was likely to give more practical results than if he had bound himself to the actual conditions of practice. Another point which Mr. Imray had touched upon was this: he said that the Author insured that the mixture within the cylinder should be homogeneous, and that that did not obtain in the gas-engine. Although Mr. Imray had very high judicial authority on his side, Dr. Hopkinson must differ from him on that point, as he had no doubt, unless special precautions were taken to prevent complete mixture, the contents of the cylinder of most gas-engines were practically homogeneous at the time of ignition. To the majority of mechanical men it would appear that it must be so. If the velocities with which the gases entered that cylinder were considered—a velocity of 60 or 80 miles an hour—it would be seen that the entering gases would be projected forward against the piston, and there would result such a turmoil as to render the mixture within the cylinder sensibly uniform. That was really apart from the questions with which the Author had dealt. Mr. Imray also said that the Author had omitted another condition of the gas-engine, which was that in the gas-engine there were present, besides the active gases, gases which were inert. Surely, if Mr. Imray would look at the numbers at the side of the diagram, he would see that, in many of the mixtures used by the Author, there was a very large proportion indeed of inert gases—not only the nitrogen of the air used, but an excess of air with its oxygen and nitrogen together. It had been shown in the Paper that there were three theories to explain the undoubted fact that the whole heat of the combustion was not accounted for by the maximum rise of pressure. The Author pointed out diffi-

Dr. Hopkinson. culties which arose in any one of those three theories, and finally brought forward one of his own, the essence of which was that the phenomenon depended not wholly upon dissociation, but very largely also on combustion going on slowly owing to dilution. He illustrated that by the case of a coal-fire. That was hardly a thoroughly apt illustration of the point as Dr. Hopkinson took the point to be. It was well known that, in any chemical reaction, time elapsed before that reaction was complete; at first the reaction went on rapidly, but afterwards the molecules of the re-agents did not meet with their fellows and complete the reaction so rapidly. It was a different thing in the case of a coal-fire. He would further point out this with regard to the Author's theory, it approximated very closely to Hirn's. The result would be largely determined by the size of the vessel, by the conductivity for heat, and by the specific heat of its walls. If the mixed gases could be imagined as all enclosed in a vessel in which the walls absorbed no heat, then, by the Author's theory, the pressure should rise, at all events for the weaker mixtures, to very nearly the amount indicated by the heat of combustion. Whether that was so or not remained to be proved, but if suitable experiments were devised possibly it might be ascertained. On the other hand, taking Bunsen's theory of dissociation, if the gases were enclosed in a non-conductive envelope, notwithstanding the fact that no heat was abstracted, the pressure would not rise so very much higher than was actually found to be the case. The question of the abstraction of heat by the walls was one which might be reduced to a matter of calculation, and its effect ascertained. It would be complicated by the smallness of the conductivity of the gas itself, and by the fact that in consequence the gas in contact with the wall would be very different in temperature from the gas remote from the wall. He would say again, in conclusion, that not only was the Paper one of very great scientific value, but that, if properly used, the facts which it had brought forward would become of considerable practical value as well.

Prof. Adams. Professor W. GRYLLS ADAMS made a few remarks on the theoretical points already touched upon by Dr. Hopkinson. The Author had pointed out in this, and in his previous Paper on this subject, that 1 lb. of gas evolved on combustion about 12,500 units of heat, but that the whole of this heat was not accounted for by the resulting temperature of the gas when exploded in a confined vessel, such as that which he employed, or in the gas-engine. The Author clearly pointed out the three principal causes which had been adduced by Hirn, by Bunsen, and by Mallard and Le Chatelier of this

falling off of temperature. By the process of cooling, put forward by Hirn, the rate of loss of heat would be the same when attaining to the maximum temperature as when falling away from it. If the combustion was complete at the highest temperature, the falling curve would give the rate of loss from this point; and applying this to the rising curve, the whole of the deficiency was not accounted for, so that the process of cooling was not sufficient to account for the results. The experiments on gas-engines, in which Professor Adams had been engaged at the Crystal Palace Exhibition, bore out the conclusions which the Author had drawn from his experiments. Large and small gas-engines, having very different surface-areas, might be expected to have very different Prof. Adams.

Fig. 1.

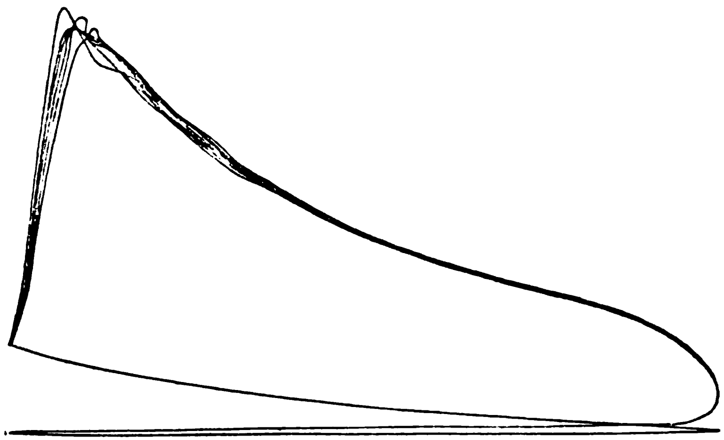


Otto 2 HP.

rates of cooling, yet experiment showed that in Otto Gas-Engines of 2-HP. and of 16-HP. (Figs. 1 and 2) the curve of pressure was almost absolutely the same. That the pressure and temperature reached in the explosion in a gas-engine and in a closed vessel were the same, was shown by some indicator diagrams taken on the Otto 16-HP. engine, when the cylinder became so heated that no gas flame was needed to cause the explosion, but the hot cylinder exploded the gases when they were fully or even partially compressed (Figs. 3 and 4); occasionally the explosion occurred and the full pressure was reached at or even before the end of the return compression-stroke, so that there was no expansion before the full pressure and temperature were attained; in these cases

Prof. Adams. the explosion was practically in a closed vessel, and the maximum pressure as well as the pressure-curve was the same as in ordinary gas-engine explosions. One special diagram taken on the

Fig. 2.



Otto 16 HP.

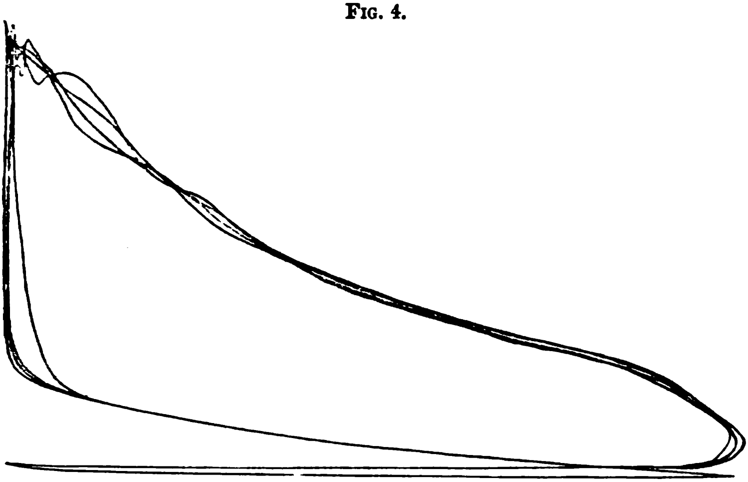
Fig. 3.

Cylinder Ignition.

16-HP. gas-engine, when the cylinder was getting hot (Fig. 5), very well illustrated the step-by-step action shown by the Author in the explosions in the closed vessel. At first these steps looked

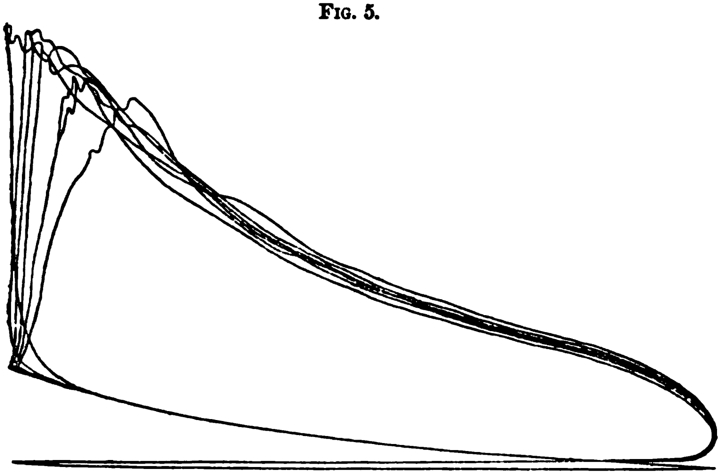
like jumps of the pencil of the indicator diagram, but they might possibly be successive partial explosions. Yet they did not occur in the same way in successive strokes, and they did Prof. Adams.

FIG. 4.



CYLINDER IGNITION.

FIG. 5.



OTTO 16 HP. CYLINDER GETTING HOT.

not seem to occur frequently in the gas-engine. Whenever the greatest pressure was attained at the beginning or at any time during the first half of the stroke, the pressure-curve was always

Prof. Adams. of the same form for the latter half of the stroke. These experiments seemed best to support the theory of Bunsen, that the temperature was limited by the dissociation of the gases, so that when a definite temperature was reached a portion of the compound gas was dissociated which entered into combination again, and was burnt when the pressure was gradually relieved by the forward motion of the piston. In this way the gas gradually burnt supplied the heat lost through the sides of the cylinder, and kept up the pressure-curve nearly to the line, which would represent the case where no heat was lost by conduction through the sides of the cylinder.

Mr. Dixon. Mr. HAROLD DIXON said he should like first of all to thank Mr. Clerk for having carried out these experiments in a way which he, as an unpractical man, could appreciate. If they had been done in a vessel with a movable piston, he was afraid that, for scientific purposes, they would not have been able to draw such good conclusions as they now could from them. With reference to a remark made by Professor Adams, about the curve shown by the Author, he thought that the curve (Plate 1, Fig. 3), caused by the action of hydrogen being exploded with the right proportion of air, really showed the oscillation period of the spring of the indicator; and if the eye were carried from that figure to the top one, and the point 3 noticed, and then the point 4, and then the final inflexion which occurred, it would be seen that those corresponded very nearly with the first, second, and third periods shown in Plate 1, Fig. 3. He was not practically acquainted with the indicator. He supposed that it had a piston moving up against a spring. Passing on from that to Bunsen's experiment, in which he exploded hydrogen and oxygen in a vessel closed by a weighted plate, he might remind the members that Bunsen estimated the explosion-pressure within certain limits by finding the weight which was just lifted by the heated gases. He loaded a piston pressing down on the plate on the top of the vessel, and then fired the mixture with a spark passing through the whole length of the vessel. Getting a silent flash when he weighted it to a certain extent, he then diminished the weight, and repeated the experiment, until he found the plate lifted, which was indicated by the noise and by the water which surrounded the top of the plate being sputtered about. He found with hydrogen and oxygen that about 10 atmospheres was the pressure necessary to restrain the explosion, and that when it was diminished to 9½ atmospheres the weight was lifted. Arguing that if the temperature of the gases was raised up instantaneously to its highest point, and if the specific

heat of steam remained constant, only one-third of the total quantity of hydrogen and oxygen could have entered into combination at once, Bunsen supposed that one-third of the gases united, and remained, as it were, in equilibrium; the other two-thirds not being dissociated so much as not being able to unite at the temperature, and then that the whole gas cooled down until a temperature was reached at which another one-third united. Bunsen supposed that the burning actually went on in that way in jumps, and not that there was a gradual combination. He seemed to have been led to this belief by some other experiments upon chemical affinity as shown in gaseous explosions. All chemists would remember the experiments which he made, beginning in 1852, in which he exploded hydrogen and carbonic oxide with oxygen insufficient to completely burn them, and found that the proportion of carbonic oxide to hydrogen might be varied within rather large limits without altering the ratio of the steam and carbonic acid produced; but on continuing to alter the proportion of the carbonic oxide and hydrogen, a sudden jump took place in the proportion of the carbonic acid and steam produced. He said that that sudden alteration was brought about by the peculiar action of chemical affinity, whereby certain hydrates of carbonic acid were formed. Those experiments of Bunsen's had been shown to be wrong, and Bunsen had admitted that they were wrong, and that the change in the proportion of carbonic acid formed when various mixtures of carbonic oxide and hydrogen were exploded with insufficient oxygen was a continuous change, and there was no sudden jump at any point of the curve. Bunsen's experiments, on which he relied for showing that a mixture of hydrogen and oxygen burnt only in successive thirds, contained errors of at least 10 per cent. Those experiments were not sufficiently accurate to found upon them such a statement, which was against all present known facts in chemistry. Bunsen had shown by an ingenious arrangement of a revolving wheel with slits in it, that the temperature of incandescence was kept up in this explosive vessel for about $\frac{1}{30}$ second; that was to say, light was given out by the flame for a period far beyond what was necessary for the flame to pass from one end of the vessel to the other. Bunsen used that as an argument that no considerable loss of heat by cooling could have taken place before the maximum pressure was attained, but it might also be used as an argument in favour of the Author's view, that the combination might be going on all the time, but more and more gradually as the quantity of steam increased. Mr. Dixon.

Mr. Dixon. With regard to using pressure-gauges to measure the pressure produced by the rapid explosion of hydrogen and oxygen, very large errors might be introduced by reason of the instantaneous character of the explosion. The Author explained that he heard a rap as of a smart blow with a small hammer on the end of the piston when hydrogen was exploded with the right proportion of air, and the curve to which he had just referred showed the piston jumping up and down as if it had been violently struck and then left to itself. Very great pressure might be produced momentarily, without moving to any appreciable extent a gauge loaded with a weight, as Bunsen's gauge was loaded. Messrs. Mallard and Le Chatelier, by using a much more delicate indicator, had certainly shown that pressures of 20 atmospheres and over were produced by the explosion of hydrogen and oxygen; that was to say, more than twice that found by Bunsen; and in experiments which Mr. Dixon had been making almost continuously for the last two or three years, he had found pressures which must be much greater than 20 atmospheres. He used glass tubes varying from 12 to 15 millimetres in diameter, and from 3 to 4 millimetres thick, and he found that if he allowed the explosive wave to reach any of those tubes they were shattered to fragments. He did not know what the pressure was, but it must be something much over 20 atmospheres. He might mention on that point an experiment which he made some years ago when attempting to compare the velocities of explosion of two or three mixtures of gases—carbonic oxide and oxygen for one, and hydrogen and oxygen for another. He exploded them in a small vessel connected with a U-shaped pressure-tube, containing mercury, and a little index; and he found that when using a small vessel the mixture of hydrogen and oxygen produced a greater pressure in the gauge than the mixture of carbonic oxide and oxygen. It was known that hydrogen and oxygen exploded much faster than carbonic oxide and oxygen. Again, he had exploded similar mixtures in a tube about 500 millimetres long, with the same pressure-gauge attached to the tube. In the case of the carbonic oxide and oxygen a very considerable movement of the mercury gauge took place, but when hydrogen and oxygen were substituted, there was scarcely any movement at all, the explosion was so abrupt that apparently it had not time to move the mercury. He found that the explosion of hydrogen and oxygen took place at the rate of about 2,800 metres a second, or say 3,000 yards, a result agreeing with Berthelot's determination. Messrs. Mallard and Le Chatelier had pointed out, in speaking of the instantaneous

character of the pressures produced by explosion of these gaseous mixtures, that if a pressure of 100 atmospheres could be produced, which only lasted the millionth part of a second, then a piston of 1 gramme weight, and of 1 square centimetre in area, would only be moved $\frac{1}{2000}$ part of a millimetre—something which could not be appreciated at all. He, therefore, did not think that Bunsen's experiments were conclusive, and the Author's experiments might be affected by the same error, that the gauge employed was not delicate enough to measure the highest pressures reached, which must be only momentary when using hydrogen and oxygen. He was not talking of the mixtures of coal-gas and air. But though the Author might not have measured the highest pressures actually produced in a small portion of his explosion vessel, that did not invalidate his argument drawn from the rate of cooling of the exploded gases. He thought that the Author had brought very satisfactory evidence in favour of the slow combustion of gases, as they were gradually diluted by their products of combustion, and he called to mind several cases in which there was certain evidence that gradual combination took place in gaseous explosions. In the incomplete combustions of hydrogen and carbonic oxide first studied by Bunsen, it seemed certain that the reaction first set up was the oxidation of the hydrogen to steam; afterwards, when some steam was formed, it began to react with the carbonic oxide; and finally, when some carbonic acid was formed, it began to react with the hydrogen. The first action probably came to an end long (comparatively speaking) before the other reactions were finished. As a somewhat striking illustration of gradual chemical action in gases, he might mention the following experiment. He was exploding a mixture of nitrous oxide and carbonic oxide with a quantity of steam, and observed two distinct coloured flames; first of all, the ordinary blue flame of carbonic oxide ran down the tube, and after that, all flickering about in the tube—showing that a combination of some kind was still going on—there was a distinct green flame lasting very much longer than the other. There was a case in which gradual combination in explosive gases was certainly taking place. Mr. Dixon.

Mr. WILLIAM FOSTER said it was more easy to criticise than to add to information on the subject of the Paper. It appeared to him that the Author had commenced on safe ground, that was to say, in making experiments in closed vessels at constant volume. In dealing with explosive mixtures in vessels, in which the volume of the gases was changing and doing external work, it would be an extremely difficult thing to measure heat-quantities, in consequence Mr. Foster.

Mr. Foster. of the inequalities of such conditions. With reference to information that had been afforded of late years with regard to explosive mixtures, he might cite an opinion current seven or eight years ago, prior to the accident at Tottenham Court Road. Experiments made prior to that date led to the belief that the velocity of the propagation of flame was slow. No doubt the disastrous circumstance he was referring to led to an inquiry, and Mallard and other experimenters had since given the world considerable information which revealed a new and unexpected order of things. Therefore there was a great deal to be learnt, even from such abstruse inquiries as these. It was interesting to note that the maximum pressure which the Author recorded was obtained by means of a mixture in which the oxygen was very largely in excess. He did not himself like seriously to offer any opinion on the matter which had been brought forward, but it did seem that the cooling produced by the walls of the vessel, in which the explosion occurred, must have a very considerable influence on the result. Having regard to the specific heat of the gases, and the relatively large capacity for heat of the enclosing vessel, it must follow that there was a considerable loss of heat in that way; and that if the temperature of the explosive gas were reduced and the tendency to combustion minimised, the condition was one tending to lower the total heat produced below that which was theoretically possible. The Author did not refer to any experiments (which no doubt had been made) on the actual composition of the effluent gases after the explosion. Probably such were on record, and he should like to know whether, supposing incomplete combustion to occur, it could be shown in the nature of the effluent gaseous products, *i.e.* whether it would be found in the condition of the carbon compounds. In burning ordinary coal-gas, unless the flame had perfect freedom, so to speak, incomplete combustion occurred. In the familiar gas-stove, used for boiling and heating water, it was well known that incomplete gaseous products made their appearance, and were extremely detrimental. The same conditions must occur in the gas-engine—there must be the cooling influence; and it was an important matter to know whether there was a serious amount of heat-energy still available in the gases due to incomplete combustion. He would suggest that if the Author had given a set of curves with carbonic oxide gas in a fairly pure state, and a set of curves with marsh gas in a fairly pure state, they might have shown valuable results. Those two gases were among the chief constituents of any illuminating gas. Carbonic oxide was a gas which did not naturally produce steam in its combustion; and

dealing with carbonic oxide and oxygen the result would be a gaseous product, which was not condensable under the circumstances. Of course he was aware there would be little if any steam condensed in the case of mixed gases. But it was possible the curves producible by an explosion of carbonic oxide and oxygen (where steam was absent) on the one hand, and marsh gas on the other, might throw some light on the question. Speaking of gauges, the same idea occurred to him as had been expressed by the last speaker, that it was the inaccuracy of the gauge which gave rise to that particular set of results. Take for instance an anemometer—a gauge could not be used there in the ordinary way; some special device must be resorted to. In the case of a vertical gauge the inertia of the fluid would prevent indications of sudden puffs or pressures; and the inertia of the spring would show itself in a violent explosion, as was evidently the case with hydrogen and oxygen. Mr. Foster.

Mr. W. Anderson (of Erith) said he did not understand the correction that had been made for what was termed the latent heat of steam, because, so far as his chemical knowledge went, he believed that when hydrogen and oxygen combined, the resultant water was in the form of vapour. The specific heat of steam differed considerably from the specific heat of a perfect gas, and therefore it would be interesting to know what figures the Author had taken in arriving at the results which he had tabulated. With respect to the peculiar indentations in the curve, he agreed with one or two of the speakers that they were due almost entirely to the indicator. It was a common thing to notice similar indentations in fast-running steam-engines; but at the same time he would draw attention to the fact that in the discharge of artillery it had been satisfactorily established that a serious wave-action took place, *i.e.* the pressure of the powder gases was not a steady pressure, but it was one in which there was a certain amount of oscillation backwards and forwards, and if similar action took place in the explosion of gases it would account for the irregularity of the ascending parts of the indicator curves. He agreed with the Author in his views respecting the nature of the combustion which took place with explosive substances, but must take exception to his speaking of a flame, as if it were a material substance. He did not suppose that the Author intended that it should be looked upon as such, for it was only the effect of a certain vibration of the luminiferous ether rising to a pitch to produce the effect of light. According to his view, the point of ignition set up vibrations in the ether, which travelled with immense rapidity through the Mr. Anderson.

Mr. Anderson. explosive substance, transferring its motion to the particles of the substance, and necessarily producing fresh vibrations emanating from each point where chemical union took place. These vibrations spread themselves with ever-increasing intensity till the whole chemical reaction was completed, and then became enfeebled by communicating their energy to the containing vessel that was by being cooled. If this view were correct it would lead to the inference that simple substances, such as hydrogen and oxygen, would combine with more energy than compound substances, which had not only to combine, but had also to be decomposed, and hence the fact that the combination of hydrogen with oxygen was more violent than that of coal-gas with the same substance. The illustration which the Author had given of the difference between the combustion of solid coal and coal powder might have been extended still more happily, if he had compared the combustion of coal in an ordinary furnace with the combustion of coal in the Crampton furnace. The difference was marked. In the Crampton method of burning the coal, the fuel was ground almost to an impalpable powder, and mixed with the proper quantity of air, so that it burst into flame instantly on reaching the furnace, and the result of the intimate manner in which the particles of oxygen were brought in contact with the particles of carbon, was that the temperature reached was enormously greater than that produced in the ordinary manner in a furnace. The difficulty in the process arose from the impossibility of finding refractory material which would withstand the temperature. He had experienced this himself in attempting to apply dust fuel to a marine boiler. It would appear that in the mixture of explosive gases something similar took place; although the mixture might be tolerably intimate, it was not so intimate as to ensure that each particle of the gas was in close proximity to the necessary amount of oxygen to combine with it, and therefore there would be a certain amount of delay in combustion, and this delay would be aggravated if the mixture were diluted with excess of air and products of combustion. He therefore thought that the Author had really hit upon one more cause of the discrepancy which existed between the observed and the theoretical pressures exhibited by the explosion of gases.

Mr. Bamber. Mr. E. F. BAMBER had studied the Paper with great interest and satisfaction, and thought that the curves exhibited by the Author were of a most valuable character, explaining as they did exactly what took place if a certain amount of gas and air was first put into a cylinder, then heated to the temperature of ignition, pro-

ducing combustion and a certain amount of heat, and finally losing the heat in various ways. One curve which he thought of very great importance was the curve *a* in Plate 1, Fig. 2. Taking Mr. Mallard's mixture, the velocity of ignition of the mixture exploded in the (*a*) experiment, which was similar, would be at the rate of about 1 metre per second, and using his formula for calculating the temperature of ignition, namely the temperature to which gases had to be raised before they entered into combustion, he found that it was something like 800° or 900° Centigrade. The strange part of the matter was that up to 0·40 second the temperature had only risen to the temperature at which gases had to be ignited: the whole of this time the gas had been as it were fighting in order to keep up to the temperature of ignition; every particle of gas that had been coming on had been reducing the temperature that had been produced by the portion of the gas that was exploded previously. So that the temperatures were very low; there was no heat of combustion available to raise the productions of combustion above the temperature of ignition until they came to the 0·45 second; then the combustion only lasted a short time, and finally the curve fell again. He did not mean to say that the temperature during that time had not been higher than was shown on the diagram. There had been as it were two forces at work: one, the heat produced by combustion, had been tending to pull the curve up, whereas the other force—the heat absorbed in raising the particles to the temperature of ignition—had been pulling the curve down; so that the result was the curve *a* represented in Plate 1, Fig. 2. Compare this curve with *g* in Fig. 2, or *e* in Fig. 1; in this case the temperature of ignition was lower, but the heat produced by combustion after ignition was of much higher intensity, so that the curve was not pulled down so much as in the previous instance, and hence it followed that the maximum temperature was much higher, was gained much more rapidly, and the temperature was maintained above the temperature of ignition much longer. The Author had referred to the various opinions that had been expressed as to the reason why the temperatures and pressures obtained in combustion were not the real temperatures and pressures that should be obtained if the whole of the heat were available for the purpose of raising the pressure or raising the temperature of combustion. The Author thought that the dissociation theory referred only to certain cases, and in that he agreed with him. He was quite sure, for example, that in the curve *a* dissociation must have had very little, if any, influence; but in curve *g* it doubtless had had considerable influence. The Mr. Bamber.

Mr. Bamber. Author had also referred to the theory of Hirn as to the cooling of the gases by the heat radiating out through the walls of the cylinder in which the combustion took place, and for various reasons he was satisfied that very little influence was due to that cause. The main reason which he gave was that when cylinders varied so much in size as from 4,000 to 300 cubic centimetres, the amount of the loss of pressure was found to be very much the same in each. The Author had also considered the question of increase of the specific heat of gases, being of opinion from the result of his experiments that it was not increased. In the other two points he was disposed to agree with the Author to a certain extent, but in regard to the specific heat of the gases he was convinced, from the large number of experiments made by various observers, that the specific heat really did rise. The main reason assigned by the Author for his opinion was that if the specific heat rose in that way there would be a larger quantity of heat evolved at the lower temperatures than at the higher, which was not the case. The fact was, however, as he thought, that the specific heat of the gases was certainly rising as the higher temperatures were reached, but there was a larger amount of heat being produced at the same time, so that the curve was kept in nearly a straight line, as in the case of *a*, Plate 1, Fig. 1, and Plate 1, Fig. 2; because the rate at which combustion was produced was sufficient to overpower the rate at which the increased specific heat of the gases was absorbing the heat, so that the curve practically kept parallel to the base line. He most certainly agreed with the Author's explanation of the change of continuity of the gas curves. To his mind it clearly implied a sudden reduction in temperature due to an abnormal absorption of heat, and it was doubtless caused by the breaking up of the hydrocarbons into their elements. The Author thought that the curves *a* and others did not represent the total amount of the heat the gases could evolve, and that if they did, those curves, instead of being of the shape represented, would be parallel to the base line at the highest point to which the curve rose. The main reason assigned was that, although the whole of the inside of the cylinder was full of flame, the whole of the gases there did not combine, and therefore complete combustion did not take place; just as in a fireplace the whole of the fuel might be in a state of ignition, but the whole of the heat was not given up, because there was a portion of the fuel that had not entered into combustion, and might never enter into combustion before the fire went out. No doubt there was an action of that kind taking place, and Mr. Berthelot, and before him Bunsen, had

made experiments in which they had calculated precisely what was the quantity of gas in the cylinder which had combined; and so far the Author agreed, if he had understood him aright, with other observers who had already treated the subject. Another point made by the Author was that the dilution of the gases, through the products of combustion which had already combined, prevented to a certain extent the remainder of the gas from combining, and for that reason the curves were not parallel to the base line. In all those points he thought that he could agree with the Author. But if the Author found by chemical analysis that the whole of the gases had been burnt, he was certainly puzzled to understand his reading of the curves. In that case he should think that the enormous mass of matter of the cylinder in which the explosions took place, being probably three thousand or four thousand times greater than that of the combining gases, must be absorbing the heat, and radiating it into the atmosphere nearly as quickly as it was produced, and so preventing the temperature and pressures rising within the cylinder; in a calorimeter the whole of this heat would be absorbed by the surrounding fluid. The subject of the temperature of ignition was a very interesting one, and one which he had long studied. If in a gas-engine, or other motor engine, after explosion had taken place, some means could be employed to utilize the heat that had not been used in producing pressure and moving the engine piston—if it could be brought back again—the curve of pressure might be raised, and greater pressures might be obtained. The only way in which it could be done was by making use of the waste heat of the products of combustion, and in that way increase the total work. In the case of the well-known regenerative gas-furnace, the heat was raised in that way, and it was also done in the case of regenerative gas-burners. There again an interesting physical circumstance had to be considered, namely, that as soon as the temperature was raised, energy of a different character was produced. Instead of the yellow light produced in the ordinary gas-burners, there was a very bright white light. Of course for heating purposes it did not do to carry too much of the heat up to such high temperatures as would produce light, which was another class of energy, as, if in an area of energy a certain portion represented light, it must reduce the quantity available as heat. In the early days of electric lighting, it would be remembered that an exceedingly blue light was produced, and the effect was due to the production of a temperature so high that actinic action was produced instead of the light action desired, and the maximum of light was not got that might be

Mr. Bamber.

Mr. Bamber. produced out of the electric energy employed. The Paper was not only valuable for the facts that it recorded, but for the amount of thought that it contained, and it was very gratifying to have a Paper of that class brought before the Institution.

Sir J. Douglass. Sir JAMES N. DOUGLASS said it would add considerably to the value of the Paper if the Author would furnish some information relative to the composition of the most efficient gas, in regard to its cost, for use in the gas-engine. The commercial value of coal-gas, as manufactured in this country for illuminating purposes, was nearly in the ratio of the number of candle-units produced by the combustion of 5 cubic feet per hour, in a standard statutory burner. Glasgow gas had an illuminating power of 27 candles, and Oldham gas had an illuminating power of $18\frac{1}{2}$ candles. The commercial value of Glasgow gas was thus 46 per cent. higher than that of Oldham gas. It would, however, be observed by the Tables, pages 4 and 5, which had been calculated from the curves of explosion from different mixtures of the Glasgow and Oldham gases with common air, that with five mixtures of each of these gases and air, namely, $\frac{1}{14}$, $\frac{1}{12}$, $\frac{1}{10}$, $\frac{1}{8}$, and $\frac{1}{6}$ of gas to 1 of common air, the average pressure produced was practically equal, and that these two gases were of nearly equal commercial value for the purpose. These results would appear to point to further experiment, for the purpose of determining the most economical gas for use in the gas-engine.

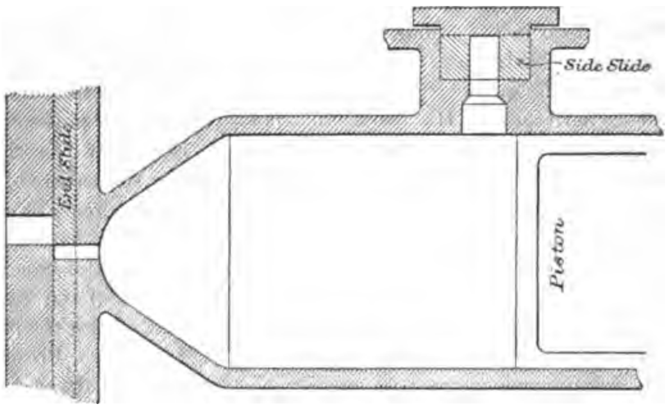
Mr. Willis. Mr. R. H. WILLIS thought it would help the members to understand the Author's cards if he would explain the effect of exploding the mixture at different points in the vessel with respect to the indicator. The cards had all been taken with the indicator at one end of the vessel and the ignition points at the other end. If experiments had been made with ignition at other places in the vessel, there would probably have been a variation in the shape of the card. He made that statement because he had made some experiments with an apparatus somewhat similar to the Author's, but he had a piston so arranged that at the time of ignition the gases were in motion from its mechanical action, and were exploded by a red-hot surface, and he had found very much difference in the time of explosion according to whether the gases were in motion to or from the place of ignition. He could delay the explosion probably for a second by having sufficient velocity of current towards the igniting point. That seemed simple enough, and it corresponded with some of the experiments on ignition in tubes; but he had found the result so marked, even in the larger vessels, that he thought it would be interesting to know what

results the Author had obtained in that way with his apparatus. Mr. Willis. He had found, no doubt like every other experimenter, that the inertia or the momentum of the air had a great effect upon the experiments. As a great deal turned upon the question of indicator cards, it would be interesting if the Author would state which indicator he had used, different results being often obtained from different indicators.

Mr. D. CLERK, in reply to the discussion, observed that the Mr. Clerk. experiments described in the Paper were made to obtain data required in his daily practical work upon the gas-engine. Since April 1882, when he had the honour of laying before the Institution his Paper upon "The Theory of the Gas-Engine," more than three hundred and fifty compression-engines of his design had been constructed, ranging from 2 to 20 effective HP., and now employed in every variety of work from wood turning to electric lighting. The experience gained in superintending the construction and testing of many of those engines, proved to him in the most emphatic manner the necessity for accurate knowledge of the nature of gaseous explosions. Engineers had so long possessed accurate numerical knowledge of the properties of steam that it was difficult to realize that there was a time when but slender data existed. It was only by long and laborious research, conducted simultaneously in the engineer's workshop and the laboratory of the man of science, that the present complete knowledge of steam had been attained. The science of the gas-engine was still in the rudimentary stage, the greatest ignorance prevailed of the nature of the working fluid, and till accurate knowledge of the times, pressures and temperatures of explosion of gas and air under all circumstances was attained, practical progress would be slow. He considered the data given by his experiments as a small contribution to the pressing necessities of the gas-engine designer; indeed, so far as he knew, they were the first published figures of the pressures and temperatures of coal-gas and air explosions. Knowing so familiarly the needs of the gas-engine designer, he was a little surprised at Mr. Imray's criticism of the Paper as unpractical. He could only suppose Mr. Imray's opinion to arise from his want of practical acquaintance with gas-engine work; if he remembered aright, he had heard him state a few months ago that he had no experience whatever in the construction or design of gas-engines. Still his experience of the steam-engine should surely have taught him that the cylinder of an engine was not the best place for determining with accuracy the properties of the working fluid used. The properties of steam had

Mr. Clerk. not been determined in this way, but in separate vessels, and often in glass tubes. The fact that a moving piston was absent did not vitiate the results, but was necessary for accuracy. His experiments had been conducted in such a way as to have all the conditions measurable, and so to obtain indications which could be accurately understood. The closed-vessel explosions being thoroughly under measurable circumstances explained the explosions in the working cylinder, and enabled him to predict exactly what happened in the gas-engine cylinder, and to know the effect of any given change in the engine upon the power used to drive it. Mr. Imray was mistaken in supposing the other circumstances of the experiments as differing from those existing in gas-engines; the mixture in gas-engine cylinders was not hetero-

Fig. 6.



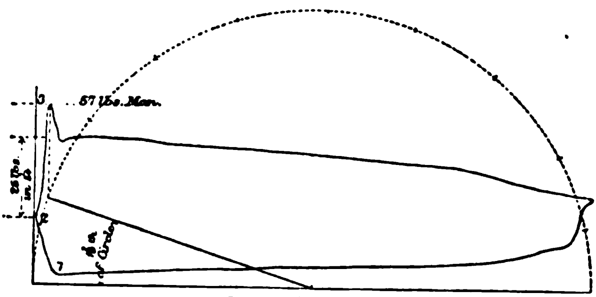
geneous but practically homogeneous. He had carefully examined the contents of the Otto and Clerk engine cylinders and found practical homogeneity in the cylinders, the mixture being easily explosive at the piston as well as at the admission port. The supporters of Mr. Otto's views, including Mr. Imray, had produced not the smallest fragment of evidence in proof of their assertions beyond an analysis from one of his engines, under conditions of adjustment which certainly were not those of ordinary work; and even this analysis was publicly declared by the chemist who made it to be inaccurate and unreliable in its details. Experiments which were made by him on an Otto engine at the works of Messrs. Crossley, under the conditions imposed by themselves, were convincing to those acquainted with the subject. An ordinary Otto engine was fitted with two igniting valves, Fig. 6, one valve on the

side of the engine at the end of the explosion-space next the piston, the other in the usual position at the end of the cylinder. If Mr. Otto's hypothesis were true, that the gases next the piston were non-explosive and served as an "inert fluid," in Mr. Imray's words, "to utilize the heat produced by the combustion," it was obvious that the valve next the piston should not explode the mixture there. What happened? That valve worked as well as the other; the mixture there exploded with perfect regularity; the valve was improperly set, and he asked that the setting should be slightly changed; this, however, the Messrs. Crossley declined to do. He could then and there have worked that Otto engine with explosion equally good from either end of the cylinder had he been allowed to do so. This ought to be enough to convince any one who considered the subject of the practically homogeneous nature of the charge in the gas-engine cylinder. He agreed with Dr. Hopkinson in his remarks on the nature of the charge in the gas-engine cylinder, and he was exceedingly pleased to find so good a scientific authority at one with him on the practical nature of his experiments. He owed an apology to Dr. Hopkinson for the "coal fire" illustration; it was, as he said, not a strictly analogous case, but it assisted his mind in grasping the nature of the action occurring during explosion, which permitted increase of pressure after the explosion had filled the whole space with flame. He did not consider Hirn's hypothesis a correct one; the check to increase was due to something besides cooling action of the walls; undoubtedly the rate of combination changed greatly after the flame had spread throughout the whole vessel. No doubt, too, Professor Grylls Adams was correct in stating the similarity between gas-engine curves and those produced by his experiments; so far as the explosive part of the curves shown by the rising line, the precise similarity could not fail to be observed. The phenomena of gas-engine explosion were precisely reproduced there under measurable conditions. He was in complete accord with what Professor Grylls Adams said of the dissociation theory; but those experiments discovered some new actions which he was not aware that any previous experimenter had observed. He was fully convinced that the pause in the explosion curve in Plate 1, Fig. 1, was not due to any trick of the indicator; when he first observed it he shared the opinion of Mr. Harold Dixon and Mr. Anderson, and supposed that the indicator had failed. A careful set of experiments with the indicator and some calculation convinced him that the change was a real one, and represented a change actually occurring in the cylinder. The Richards indicator was very sensitive. The Mr. Clerk.

Mr. Clerk. united weight of the piston and lever of an indicator in his possession was 0·089 lb. or less than $1\frac{1}{2}$ oz. Using the forty-eight scale spring, the distance moved to register 1 lb. by the piston was $\frac{1}{192}$ inch or 0·000434 foot. The area of the piston was $\frac{1}{2}$ square inch. If 1 lb. per square inch were applied to this piston in an infinitely short space of time, in fact instantaneously, the inertia of the mass would cause a retardation of $\frac{1}{300}$ part of a second; the pencil would not register 1 lb. pressure per square inch till $\frac{1}{300}$ second had elapsed.

A pressure of 48 lbs. per square inch applied instantaneously would not be registered till $\frac{1}{300}$ second late; but the velocity would be such at that point that it would carry very considerably past the true pressure; the amount which the pencil passed the true pressure measures the error of registration. Now in Plate 1, Fig. 1, point 4, curve *e*, about 0·03 second had elapsed since the start of the pencil, or ten times the time required to register 48 lbs. per square inch, and at the point of maximum pressure no oscillation

Fig. 7.



Steam Engine.

Diameter of cylinder 8 inches, length of stroke 10 inches, revolutions 170 per minute. Boiler pressure 58 lbs. Scale $\frac{1}{80}$.

whatever occurred. In the curves *d*, *c*, *b* the points 4, 4, 4 were distinctly marked when the pencil was moving in such leisurely fashion that error was impossible. The same thing was observed in Plate 1, Fig. 2, curves *e*, *f*, *g*, *h*, *i*.

If oscillation caused the pause, why did it not appear in curves *b* and *c*, Plate 1, Fig. 3, hydrogen and air?

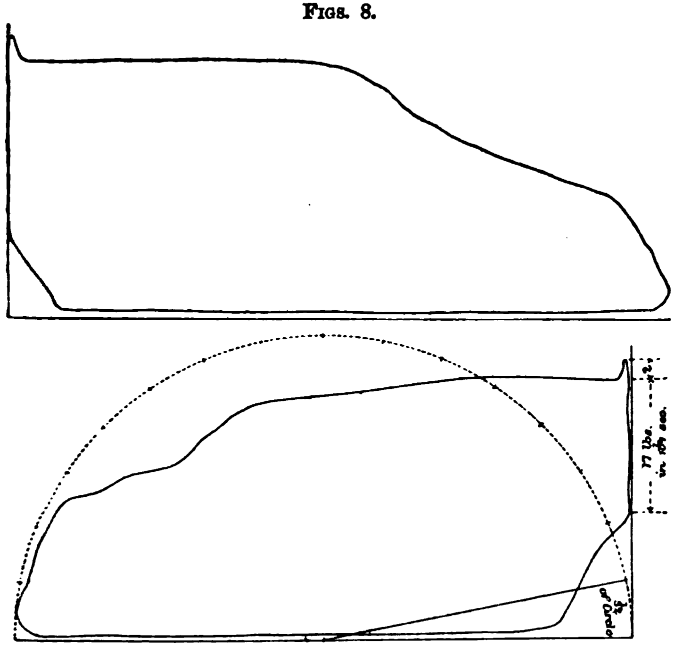
Here there was no trace of this pause, the real effect of oscillation was seen at *c*, Plate 1, Fig. 3. He thought that Mr. Anderson was mistaken in supposing such check in the rising curve to be common in steam diagrams. He had never observed anything of the kind.

Fig. 7 was a steam-engine card taken by him with the engine making 170 revolutions per minute; at the point 1 compression

commenced, and at 2 the steam admission commenced; at 3 the pencil marked a pressure somewhat above the true pressure attained, and due to the velocity attained by the indicator piston. Mr. Clerk.

Figs. 8 were from cards from the two ends of the cylinder of an engine running at 200 revolutions per minute; here a precisely similar rise above the true pressure was observed, but not the slightest approach to a pause in the rising curve. He had examined fifty diagrams taken from steam-engines at high-speed, and

FIGS. 8.



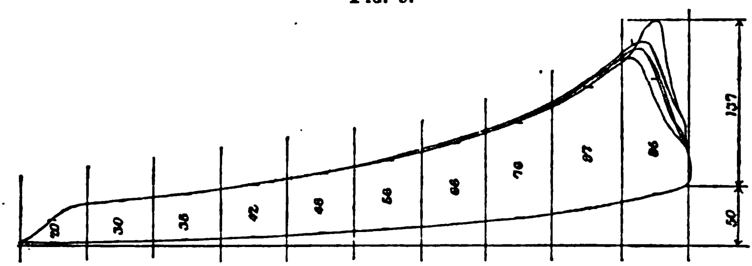
STEAM ENGINE.
6 inches × 12 inches. 200 revolutions per minute. Scale of spring $\frac{1}{16}$.

had been unable to find any appearance similar to the check at Plate 1, Fig. 1, marked 4.

Gas-engine diagrams exhibited such a break very often indeed, in the most unmistakable manner and at all rates of revolution. Fig. 9 was a diagram of the kind, showing most distinctly a change in the rate of the increase of temperature some time after the commencement of the explosion. Fig. 10 was another specimen even more marked. He did not suggest that the indicator was sufficiently sensitive to prove that an actual fall of pressure occurred at the point 4 in Plate 1, Fig. 1; but he had no hesitation

Mr. Clerk. in stating that it proved a very abrupt change in the rate of combustion at or near that point in time. Such a change could only occur after the vessel was filled with flame. Coal-gas being mainly a mixture of hydrogen, marsh gas and other hydro-carbons, it seemed as if in the early stage of the explosion-line the free hydrogen was rapidly inflamed, the marsh-gas and other hydro-carbons acting at first the part of diluents and not actually entering into combination with oxygen, but merely being heated

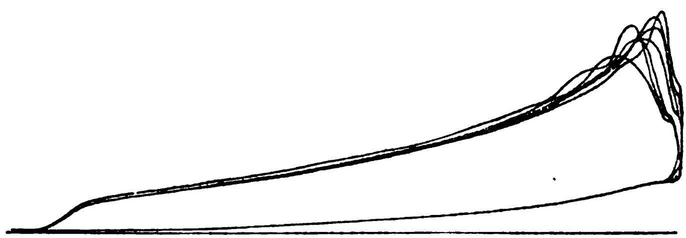
Fig. 9.



From 6 HP. Clerk Gas Engine.

I.HP. = 9·88. Consumption = 22·26 cubic feet. Revolutions 150 per minute. Mean pressure 56·5 lbs.

Fig. 10.



From 6 HP. Clerk Gas Engine.

up, like the excess of nitrogen and oxygen, by the heat evolved from the combustion of the hydrogen. When the vessel was filled with flame in every part, at the temperature of about 1,300°, the hydro-carbons decomposed, and the liberation of free hydrogen and carbon caused a further increase of temperature. It was important to grasp the idea that temperature could increase after the vessel was filled with flame. He had often noticed an effect in his experiments similar to that observed by Professor Grylls Adams, at the Crystal Palace, namely, the step-by-step explosive action; it always appeared when a gas-engine cylinder was very hot. This was more marked in compression engines, but was also quite noticeable

in non-compression engines. In the Lenoir engine also the deficiency of pressure was as great as in the Otto or Clerk; and quite as large a portion of the total heat of the gas remained to be evolved after the completion of the explosion, or on the expansion, during the stroke. The following were the results of a careful test of two hours' duration made by him in London on the 4th of December, 1885, with a Lenoir gas-engine of 1 HP.:— Mr. Clerk.

Cylinder, 7⅛ inches in diameter; length of stroke, 11¾ inches.
Average revolutions during test, 85 per minute.
Gas consumed in one hour, 86 cubic feet.
Load full on, indicated HP., 1·17 (average of 9 diagrams).
Gas consumed per indicated HP. per hour, 73·5 cubic feet.
Gas and air cut off at the back of cylinder, 0·4 stroke.
" " " front " 0·55 "

Making allowance for the temperature of the cylinder and of the residual gases in the ports, the mixture used during test was of average composition, 1 volume of gas to 12·5 volumes of air and other gases.

The maximum temperature of the explosions was 1,100° to 1,200° Centigrade.

The proportion of the total heat present accounted for by the explosive pressure was 60 per cent., and the remaining 40 per cent. was evolved during the expansion.

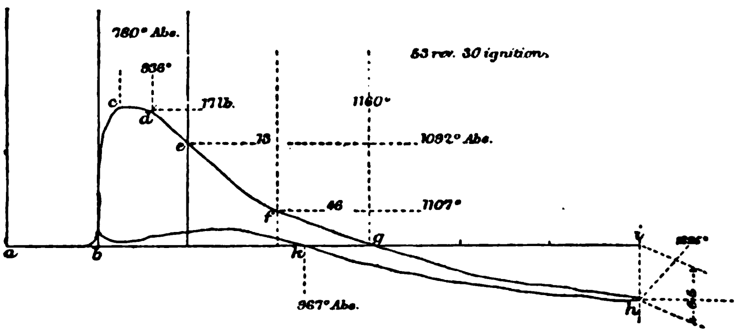
The expansion-line of the Lenoir diagram fell considerably below the adiabatic, and this fact had somewhat misled several previous experimenters, including notably Mr. Tresca, Dr. Slaby of Berlin, and Mr. Schottler, who had written an able work upon the gas-engine. The cause of this fall was the relatively large surface necessarily exposed in a non-compression engine and the slow rate of piston movement.

A test made by him with a 2-HP. Otto and Langen atmospheric-engine proved that compression was not the only method of keeping the expansion-line above the adiabatic. The test was made with Oldham coal-gas at Hollinwood on the 12th of August, 1884.

Fig. 11 was a diagram taken with a dilute mixture. From *a* to *b* the piston was taking in the uniform charge of gas and air; at *b* the admission closed and explosion occurred; the pressure only rose to 17 lbs. above the atmosphere, and the temperature, which was 780° Centigrade at the beginning of the stroke, gradually increased, becoming successively 930°, 1,093°, 1,107°, 1,160°, and 1,225° absolute Centigrade at the end of the stroke; here was an instance of a line not merely keeping above the adiabatic but rising far above the isothermal, the temperature actually increasing from

Mr. Clerk. the beginning to the end of the stroke. It was almost needless to observe that the deficiency at the maximum pressure point on the diagram was excessive, not 25 per cent. of the total heat being then evolved. He had studied Mr. Harold Dixon's Paper on explosion with very great interest, and he agreed in considering that Bunsen's conclusions on the nature of explosive combinations were erroneous; combustion did not proceed in the stages he supposed. The diagrams from the closed vessel should have shown on the descending line a series of plateaus and descents alternating instead of the uniform falling line. The production of great local pressures in a long tube was quite possible, and to his mind was clearly proved both by Berthelot's researches and by those of

FIG. 11.



OTTO AND LANGEN GAS ENGINE.
Scale of spring $\frac{1}{12}$.

Mr. Dixon. This was what Berthelot called the explosive wave. When a mercury-gauge was used undoubtedly such pressures might occur without being registered. The mercury-gauge was very untrustworthy as compared with the Richards indicator. Mr. William Foster had asked for analyses of the products after explosion; in the strongest mixtures he had not made such analysis, because there could be no doubt of the completest combustion; in the weakest mixture the combustion was not quite complete, about 0·5 per cent. of the gas present remaining unburned. He was continuing experiments on this point. However, the error introduced was slight even in the weakest mixture. He was also making experiments upon carbonic acid and oxygen; but they were not yet advanced enough for publication.

The curves given had been repeated at least six times for each experiment. The specific heat of the mixture of CO_2, H_2O, and N and O were taken at constant volume as 0·200 (p. 11).

The specific heat was only used to find the temperature which should be given by the explosion if all the heat was evolved; the observed temperatures were calculated from the pressure of the explosion. Mr. Clerk.

$$T^1 = \frac{P^1T}{P}.$$

P pressure absolute before ignition.
P^1 pressure of explosion.
T temperature before explosion (absolute).
T^1 temperature of explosion (absolute).

Take as an example the Table on page 6, Glasgow coal-gas and air-mixtures, experiment A.

$$P = 14\cdot7.$$
$$P^1 = 14\cdot7 + 52 = 66\cdot7.$$
$$T = 18^\circ + 273^\circ = 291.$$
$$\text{and } T^1 = \frac{66\cdot7 \times 291}{14\cdot7} = 1320^\circ \text{ Centigrade absolute.}$$

This was 1320 − 273 = 1,047° Centigrade, the temperature of the explosion, calculating it from the pressure produced; that was using the closed vessel as an air thermometer. Regarding the latent heat of steam, Mr. Anderson need only be reminded that the determination of the heat of combustion of hydrogen in oxygen was made by a calorimeter, and that water being used in it, the steam formed was condensed to the liquid state. The 34,170 heat-units evolved by the combustion of unit weight of hydrogen included therefore 9 × 536 = 4,824 heat-units, the latent heat of the steam formed, which was necessarily measured by the calorimeter. This heat, although evolved by the combustion of H and O as well as the rest, was not available to raise the temperature of the steam pressure, and so required to be deducted.

The remarks by Mr. Anderson on the Crampton coal-dust furnace were very interesting; no doubt temperatures closely approximating those of explosion could be obtained in that way.

He was pleased to find that Mr. Bamber substantially agreed with him in the conclusions at which he had arrived. On the fact of increase of specific heat he differed. No doubt specific heat might increase somewhat, but as yet he did not see that any proof existed to show that it did change to any but the smallest extent.

The candle-power of the gas used was:—Glasgow, 26 candles, Oldham, 17 candles. Glasgow gas, in consequence of its power of sustaining pressure better, gave a better result per indicated HP. per hour than Oldham gas, less gas being required

Mr. Clerk. to give equal pressure, but not quite in proportion to relative illuminating powers. The effect produced on the card by change in position of the firing points was small, unless with peculiarly shaped vessels. In some shapes the ignition might cause more mechanical disturbance, and therefore be sent more rapidly through the mass; a result resembling Berthelot's explosive wave might then occur, which caused the phenomena attributed by Mr. Willis to the inertia of the air. The explosive part of the curve might be considerably modified by mechanical agitation of the gases during ignition, and thus cause increase of pressure so rapid at first that the indicator might fail to register quickly enough; but the falling curve remained unaltered, and also the amount of heat evolved at first by the explosion.

As affecting gas-engines, the conclusions to be learned, in his opinion, from those experiments, were :—

That in all gaseous explosions, heat was kept back in some way, it did not all appear at the maximum temperature of the explosion. The theory of explosion, then, which supposed the Lenoir engine working without compression to have a different kind of explosion from the modern compression-engine, was incorrect. It had no foundation in fact.

The heat reserved after explosion was as great in the Lenoir engine as in the Otto or Clerk engine, and appeared on the expansion-curve in precisely a similar manner.

That greater cooling surface was the main cause of the fall below the adiabatic in the Lenoir engine was proved by the fact, that in the Otto and Langen atmospheric engine, which all admitted to use explosion, the expansion-line might even keep above the isothermal line, because of the more rapid piston movement and consequent smaller time of surface exposure.

This keeping-back of heat (*nachbrennen*) was an evil in the gas-engine; if some method of making an explosion evolve all its heat at first could be invented, great practical good would result. The efficiency of the gas in the mixture would then increase, and consequently the efficiency of the engine. The late Professor Fleeming Jenkin, in his lecture on "Gas and Caloric Engines,"[1] had clearly pointed out that compression was the cause of the modern gas-engine efficiency; in this he was at one with him, as many scientists now were, including Dr. Witz in France, and Professor Thurston in America.

[1] "Heat in its Mechanical Applications." Inst. C.E. Lectures, Session 1883–84.

Correspondence.

Mr. E. Mallard stated that the Author's experiments, made by an identical process, were nevertheless much less numerous than those of Messrs. Mallard and Le Chatelier, whose conclusions he had impugned. They were less precise, because the indicator used gave less regular figures than those they had obtained; the Author was also less exact in his discussion of the experiments which related to a subject which required generally great precision. He therefore contended that the Paper did not really contribute to the advancement of the question. The Author criticised, not their experimental results, but their conclusions drawn from those results. His strictures were based principally upon absurdities with which he had gratuitously credited them, but for which they were in nowise responsible. He could not have read attentively either their note in the "Comptes Rendus," which gave the summary and provisional results of their labour, or the complete memoir published in the "Annales des Mines." In substance the Author affirmed that, without taking count either of the loss or heat through the walls, or of dissociations, Messrs. Mallard and Le Chatelier had imagined, in order to put in accord the observation of the temperature with those of the heat of combination, an unjustifiable increase of the specific heat of the gases. Had such been the case, their researches would be unworthy of serious consideration. Had the Author read more carefully, he would have seen that, on the contrary, they had taken extreme care to measure the loss of heat due to the walls. Nearly one-half of their long memoir was devoted to the establishment, from the precise exposition and the careful discussion of each of their diagrams, of the mathematical law of the loss of heat experienced by gaseous mixtures at a high temperature when confined in a closed cold vessel. Mr. Mallard.

The knowledge of this law had in succession enabled them to prove, from the minute discussion of their diagrams, the presence or the absence of dissociation, and if present, to measure its intensity. They had thus been able to prove that, in a certain number of gaseous mixtures, dissociation did not exist, or might be neglected. In these particular cases they had, knowing the loss of heat due to cooling, been able to calculate the maximum pressures which the explosion should have developed if it had occurred

Mr. Mallard. in a vessel impermeable by heat. In the proved absence of dissociation, the maximum pressure thus obtained served them as a basis whence to calculate the true temperature of combustion; which latter served in turn to determine the specific heat of the gaseous products of combustion at the temperature of combustion.

These successive processes seemed to them to be irreproachable. Certainly they might have been deceived in the course of a very delicate and very tedious investigation, applied to nearly one hundred and fifty diagrams, and which had entailed nearly a year's work; but the Author should acknowledge the simple obligation resting upon him of discussing seriously the facts on which their conclusions were based, before characterising such conclusions as erroneous.

He would also remark that the continuous increase of specific heat of carbonic acid was perfectly natural, since this increase was shown in an unmistakable manner between 0° and 200°; it would rather be matter for astonishment if it were suddenly arrested at 200°. As regarded the increase of the specific heats of the perfect gases C, O, N, CO, it appeared to themselves less soundly established than in the case of the specific heats of CO_2 and H_2O; in any case it was much less considerable.

As regarded the novel theory propounded to explain the apparent loss of heat resulting when the observations of the pressures produced by the explosive were combined with those of the heat of combustion, the Author supposed that ignition being propagated rapidly left behind it portions of unburnt gas, which, diluted in a mass already burnt, thereupon combined with it an indefinitely decreasing speed. This phenomenon, besides being purely hypothetical, was only distinguishable from dissociation in that the latter was in equilibrium dependent upon the temperature, while the former would, on the other hand, constitute a state variable with the time. In any case, the effect on the progress of the fall of pressure would be of the same nature as that produced by dissociation. In the mixtures in which they had proved the absence of dissociation, by showing that the law of cooling was the same for high as for low temperatures, they had also proved the non-existence of the phenomenon imagined, without experimental proof, by the Author.

Mr. Rowan. Mr. F. J. Rowan remarked that the Paper was of great interest from a scientific point of view. It appeared to be certain that the limitation of the observed pressure attained in gas-engines was due to a variety of causes, of which dissociation was an important one. The distinction between inflammation and combustion was

a clear and no doubt a necessary one, but in reasoning from the phenomena observed in the case of solids, even in the fine state of division which was present in coal dust or flour, allowance must be made for the much greater facility of chemical action afforded by the much greater division of the particles of a gaseous body. In the case of a gas it was difficult to conceive that a line could be sharply drawn between inflammation and combustion. The gradual burning of an explosive mixture of gases was not easily accounted for on such an hypothesis. The Author was, of course, familiar with the late Professor Andrews' writings on the gaseous state of matter, and he would therefore ask him if the conclusions arrived at by that investigator did not in his judgment bear directly upon the questions dealt with in the Paper. He referred principally to the general law announced in the following terms: "The dilatation by heat of a body in the ordinary gaseous state, whether measured by its expansion under constant pressure or by the increase of elastic force under constant volume, is not a simple function of the initial volume or initial elastic force, but a complex function changing with the temperature."[1] The variations in the coefficient of expansion under altered conditions of temperature and pressure discovered by Andrews seemed to afford a clue to some of the Author's results, and it was possible they might explain, by analogy, the apparent anomalies in the conclusions of Messrs. Mallard and Le Chatelier referred to by the Author. There might be a critical point for gases at high temperature as there was at low temperatures, the phenomena exhibited by them changing as this point was approached. The element of pressure entered into the question in a most important way, of course. The practical value of the Author's investigations might not be directly apparent to makers of gas-engines, as the important fact to them was that only a certain pressure and temperature could be reached by the explosion of a given mixture of gases, but there was no doubt that practical work must be affected by the accumulation of light on matters of theory. Mr. Rowan.

Mr. B. H. Thwaite observed that the interpretation of the phenomena relating to the combustion of gaseous explosive mixtures, and connected with a proper development of Carnot's law, was such a vexed question that any trustworthy contribution on the subject should be received with gratitude. Berthelot had made many experiments with apparatus of great precision, and Mr. Thwaite.

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[1] Philosophical Transactions of the Royal Society of London, 1876, vol. clxvi. p. 437.

Mr. Thwaite. the results embodied in his "Essai de Mécanique Chimique,"[1] were a monument to his experimental skill. In this work he described the thermometric, pyrometric and calorimetric apparatus, used for his experiments, by which he confirmed the correctness of Mallard and Le Chatelier's theory as to the variability of the specific heats of liquids and solids with increase of temperature. Along with Vieille, he had extended these investigations to gaseous explosive mixtures, and the results and deductions had been published in the "Annales de Chimie et de Physique." These later experiments afforded supplementary evidence of the correctness of the theory as to the increase of specific "heats" of gases, with increase of temperature, explaining in a measure the cause of the difficulty of obtaining the full thermo-dynamic efficiency due to the explosion of combustible gases in gas-motor cylinders. In Berthelot's experiments, isomeric gaseous mixtures were used of such a character, that after explosion they terminated with a chemically similar constitution. The Author was of opinion, judging from the results of his own experiments, that erroneous conclusions had been drawn from these experiments of Mallard and Le Chatelier, and Berthelot, and Vieille; and the explanation of the phenomena was thus reinstated in obscurity. Unfortunately, the experiments and experimental apparatus used by the Author were not of so complete a character as to permit of rigid and indisputable conclusions to be drawn therefrom. The correct interpretation included the accurate knowledge of so many actions, not yet satisfactorily explained, that it deserved the attention of an international committee of savants in order to solve the questions once for all. Hirn's theory was upheld by Hallauer, and disputed by Zeuner. There was the law of Dalton, and that of Dulong, and Petit. Bunsen's theory of dissociation was upheld by Deville; and combated by Mr. Frederick Siemens and others. The theory of increase of specific heat, advanced by Mallard and Le Chatelier, and upheld by Berthelot and Vieille, was now disputed. There was also Avogadros' hypothesis, and Boyle and Mariotte's law, besides uncertain information relating to diathermancy and the kinetic theory of gases. Until these subjects, especially those relating to specific heat and dissociation, were more clearly understood from reliable data, it was, to say the least, premature to rigidly formulate either a law or an hypothesis. He had designed an experimental apparatus to obtain

[1] Essai de Mécanique Chimique fondée sur la Thermochimie. 2 vols. Paris, 1879.

data of a more trustworthy and complete character, using agents and apparatus of which an accurate knowledge had been acquired. Mr. Thwaite.

Professor Dr. AIMÉ WITZ, of Lille, concurred entirely with the Author's third conclusion, namely, that "combustion is very similar to other chemical actions, the first part of the reaction occurring rapidly, and proceeding with increasing difficulty as the combination approaches completion." His own researches—of which he published the results in the Annales de Chimie,[1] and in the Comptes Rendus of the Paris Academy of Sciences[2]—had even led him to formulate the same law. Thus, he had shown that a mixture of 1 volume of gas with 9·4 volumes of air required 0·21 second to achieve its complete combustion. He had further shown that with excessive dilution, combustion always remained incomplete.[3] But he could not admit that the duration of a combustion depended only on the richness of the explosive mixture, and here he differed from the Author. In fact, if a mixture of gas and air were exploded behind a movable piston, it could readily be shown that the time necessary for effecting combustion varied with the rate of expansion, $\frac{d\,l}{d\,t}$. Of this the following was a proof:— Prof. Witz.

Composition of the Mixture.	Rate of Expansion.	Time of Explosion.
	Metres.	Second.
1 volume of gas + 6·33 volumes of air .	4·30	0·045
Ditto	1·70	0·141
1 volume of gas + 9·40 volumes of air .	0·64	0·219
Ditto	0·25	0·468

The Author, by using a single closed cylinder, had not adopted a favourable mode of discovering the true law of explosion; this law could only be observed by using many cylinders of notably different volume, which he had not done. He objected that their results appeared erroneous because the maximum pressure of explosion did not diminish when using chambers of different capacities. How could the pressure diminish, seeing that its maximum value was attained in a period of $\frac{3}{100}$ second? Had he (Dr. Witz) not proved that it was the cooling of the walls which modified the time of explosion? Now cooling was not sensible at the end of $\frac{3}{100}$ second. The Author's objection, therefore, was not well founded.

The great thing that governed explosive phenomena was the

[1] Annales de Chimie et de Physique, vol. xxx. 5th series, 1883.

[2] Comptes rendus de l'Académie des Sciences, vol. xcix. 20 July, 1884; vol. c. 27 April, 1885.

[3] *Ibid.* vol. c. 10 Feb. 1885.

Prof. Witz. cooling of the walls. Dr. Witz had many times shown this to be so; he had above all shown that the useful effect reached a maximum when the rate of expansion, $\frac{dl}{dt}$, reached a maximum, and he had completely explained all the peculiarities observable in gas-engines. The influence of initial compression could only be explained by attributing it to a lesser loss of heat through the walls.

Manufacturers had applied the principles he had made known, and he proved on the 7th of November, 1885, that a gas-engine, made by the firm of Powell, of Rouen, only consumed 562 litres of gas per HP. per hour. This result was due to a strong initial compression, to a high rate of expansion, and to a high temperature of the walls of the cylinder. Practice had, therefore, confirmed his opinions, and for this reason he was constrained to think that the Author was wrong in disregarding the effect of cooling by the walls.

Mr. Clerk. Mr. Clerk, in reply to the correspondence, said he had endeavoured to state fairly Mr. Mallard's views, and was unable to discover in the Paper any substantial misstatement; he had followed Messrs. Mallard and Le Chatelier's investigations with great interest, and he did not call in question the accuracy of the experiments, which indeed his own corroborated. He quite understood that an endeavour had been made to deduce from them the mathematical law of the loss of heat by gases at high temperatures, and that Mr. Mallard's theory of increased specific heat rested on a supposed knowledge of this law; but this was the very point where he differed from Messrs. Mallard and Le Chatelier. He considered that the law of the loss of heat from a highly-heated gas to its enclosing cold walls could not be determined by observations on gaseous explosions when combustion was admittedly proceeding. In his opinion it was impossible to discover this law experimentally, unless it was perfectly ascertained to begin with that no heat was added to the gas experimented on during cooling; that was, that all the heat supplied to the gas was supplied at the moment of attaining the maximum temperature. The law of cooling deduced from the study of the falling line from a gaseous explosion could not be considered as the law of cooling of a highly-heated gas from the same maximum temperature. He agreed that Mr. Mallard's successive processes were irreproachable, but in his opinion the first step was inadmissible; it assumed the very point which should have been proved, and which could not be proved from any experiments made with gaseous explosions.

In suggesting a possible explanation of the deficit, in supposing a change in Charles's law, such as occurred at the "critical point" in carbonic acid gas, Mr. Rowan would of course have remembered that Professor Andrews' investigation was conducted at a point where the liquefaction of the gas was imminent. It was very improbable that Charles's law should fail at high temperatures; if it did, then the very means of measuring high temperatures failed; all high temperatures were measured by means of the air-thermometer, and if that was incorrect it was difficult to see how high temperatures could be measured at all. He was glad that Mr. Rowan coincided with him in the necessity of a distinction between inflammation and combustion. Mr. B. H. Thwaite was surely in error in supposing such a complete knowledge of all the complex phenomena of gases as was required to apply Carnot's law in practice. It was only necessary to know the fact of the deficit of pressure upon explosion, without understanding its complex causes, to apply practically the reasoning of Carnot's cycle. Mr. Clerk.

The fact of Professor Dr. A. Witz's agreement with his third conclusion gave Mr. Clerk great pleasure. Dr. Witz's independent experiments formed a gratifying corroboration. He was much interested in Dr. Witz's able work, "Études sur les Moteurs à Gaz Tonnant," where his experiments on explosion in a cylinder fitted with a moving piston were described. He had obtained similar results from an Otto and Langen atmospheric engine, which corroborated Dr. Witz's experiments. It was doubtless true that the cold walls regulated explosive phenomena to a very great extent, and were at present great causes of loss in gas-engines. High compression and great expansion, together with enclosing walls at a high temperature, were matters he had at all times attempted to carry into practical work. On this point he was in complete accord with Dr. Witz.

16 March, 1886.
EDWARD WOODS, Vice-President,
in the Chair.

(*Paper No. 2104.*)

"On the Economical Construction and Operation of Railways in Countries where small Returns are expected, as exemplified by American practice."[1]

By Robert Gordon, M. Inst. C.E.

A Paper was read lately by Mr. Edward Bates Dorsey, Member of the American Society of Civil Engineers, before that Society,[2] in which he stated, that while the 18,681 miles of railway in the United Kingdom in 1883 had cost over £40,000 per mile, there were at the same date 110,414 miles completed in the United States, at a cost averaging £12,400 per mile, the cost of operation for the former being about £2,000 per mile, while for the latter it was £880 during 1883. The ton-mileages of the two systems were 9,589,786,848 and 44,064,923,445; and passenger-mileages 5,494,801,496 and 8,817,684,503 respectively. Owing to differences of method in rendering accounts the mileage rates of working could not be compared for the whole; but by selecting the Baltimore and Ohio Railroad, which is the extreme type amongst the great trunk-lines of the American method of construction, with high summit-level, steep gradient and sharp curves, he found that the extra cost of working due to these difficulties was only 8 per cent.

Assuming the above figures to be fairly accurate, some corrections should be made before finally deducing a comparison. In the first place the greater portion of the English lines have double tracks, while the larger part of the American mileage is single. Again, while most of the land belonging to the American railway companies costs them nothing, and in some cases the capital accounts are reduced by sales of the land received under State grants, it is computed that in England fancy prices above the

[1] The discussion upon this Paper was taken together with that upon the two following ones.

[2] American Society of Civil Engineers, Transactions, vol. xv. p. 1.

market value of the land have added to the average cost of the railways from £4,000 to £5,000 per mile. On the other hand, inflation and watering of stock are computed to have added from £2,000 to £3,000 per mile to the actual cost of American roads. The actual charges for construction are thus brought down to, say, £35,000 per mile in the United Kingdom, and to £10,000 in the United States. Making all allowances for the differences in the value of the properties and surrounding conditions, it is evident that railway construction must be carried out more economically in America than in England and in Europe generally.

Mr. Dorsey claims that a railway can be constructed on the American system at from one-half to one-fourth the cost of the English system, and be in working order in from one-half to one-fourth the time. In the rapid opening out and development of flat countries, and especially in aiding military operations of a transitory character, these qualifications, if well-founded, are of the highest importance. An examination of the principles and of the details of the American practice, where they differ from the English, may throw light on these points, and show whether it may not be possible to introduce modifications into English practice abroad, which shall render it equally capable of satisfying the requisite conditions for securing remunerative returns and outlay in a short time.

The essential differences between American and English practice originate in the universal use by the former of the bogie-truck, with short rigid wheel-base and flexible connections between the wheels and bodies for all rolling stock, as compared with the general use of longer wheel-base and more rigid connections by the latter. The developments from this initial difference cover an immense field, and all that can be attempted in this Paper will be to select the more prominent peculiarities of the American system, so far only as they may relate to economy and efficiency of results. Notices and illustrations will be given of standard types, when these exist, as used in the latest ordinary practice; and a few examples of the extreme difficulties overcome in the alignment of roads will be added. A discussion of the principles regulating such alignment will close the Paper.

It should, however, be remembered that the working of the railway-system in North America has been undergoing a great revolution within the last few years, owing, firstly, to the introduction of steel rails and rigid fish-plates, which have been found able to bear weights and wear-and-tear much heavier than the iron ones for which they have been substituted; and, secondly, to

the very severe competition between the leading trunk lines for the east and west heavy freight-traffic, which has tested the powers and the endurance of rails and rolling-stock alike to the utmost. Bridges have been strengthened or rebuilt; loads of 40,000 to 50,000 lbs. are carried on the old cars which used to take only 20,000 lbs.; newer and stronger designs are still being produced—the 28-foot freight car is giving place to one of 36 or 37 feet in length; and while every effort is being made to keep down the dead-weight of cars to below 20,000 lbs., paying loads of 60,000 and 70,000 lbs., and even more, are regularly given to them.[1] No limit can yet be assigned to what the immediate future will show in this direction, but that the problem of freight-transport is in a transition stage is to be noted.

Against this, again, another and very powerful movement is operating. There is a strong tendency in America, in industrial processes, to adopt types capable of automatic reproduction in identical forms wherever possible. Several points of the railway-system come within the scope of this tendency. It is probable that by the end of 1886 nearly all the broad-gauge lines in the United States will be brought to the standard gauge of 4 feet 8½ inches. For some years past the Louisville and Nashville Railroad (2,100 miles long) has been prepared so that, by turning down the blank collars in the axles, all the rolling-stock can be reduced from the 5-feet gauge at a short notice. It is the practice to run cars belonging to one line over almost every other line, the owners often not regaining possession of their stock for months or years. Numerous small but important variations in the size and shape of wheels and of rails have thus acquired prominence, and the Master Car-Builders' Association, and kindred societies such as the Master Mechanics and others of the employées of the different companies, are trying to introduce uniformity of form and size in the tops of the rails and in the treads and flanges of the wheels; and a standard freight-car-truck is also the object of much solicitude.

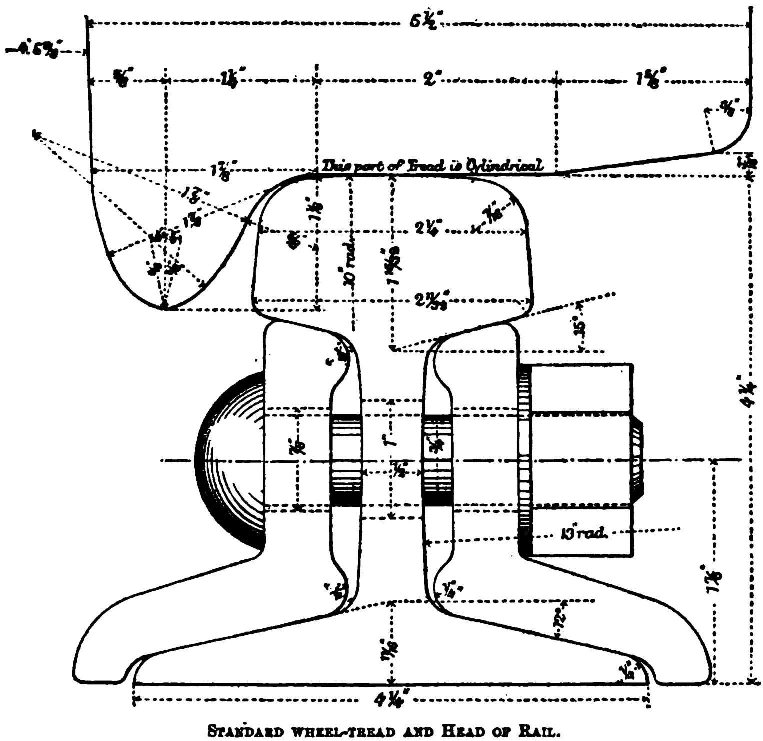
Up to the present time the only standard article universally accepted is the freight-car-axle, shown in Plate 2, Fig. 1. In 1884 its diameter was increased from $3\frac{7}{8}$ inches at the centre to $4\frac{1}{4}$ inches, and from $4\frac{3}{8}$ inches to $4\frac{5}{8}$ inches near the wheels. Its finished weight is about 400 lbs. A 33-inch chilled cast-iron wheel,

[1] Mr. Whitney says ("Railroad Gazette," 20th March, 1885), "The recent freight-car has a capacity of from 40,000 to 60,000 lbs., and it is frequently loaded to 70,000 lbs. or more. Trains on heavy grade roads are, say, sixty or seventy cars, and they are run at a minimum speed of about 18 miles per hour, and frequently "make up time" at 30 miles or more.

as hitherto generally used, is also shown, with the shape of tread and form of head of rail proposed for general adoption (Fig. 1). These forms and sizes are still under consideration; but it is probable that, with some slight modifications, they will be accepted as the universal standard throughout North America.

The increased burdens on freight-cars have severely tried the cast-iron wheel; and while those produced by the best makers

Fig. 1.



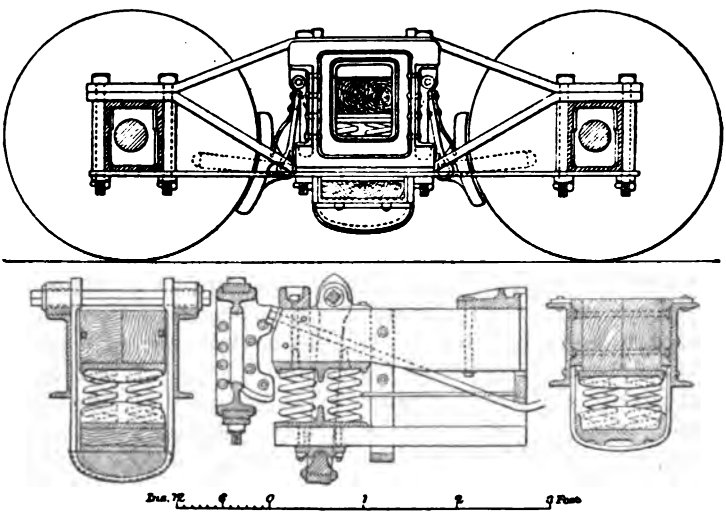
Standard wheel-tread and Head of Rail.

still yield good results of from 40,000 to 70,000 mileage averages, the general average has been reduced considerably, and on the Boston and Albany Railroad has fallen from 50,000 to 29,000 miles. There has, therefore, been a tendency of late years to resort to steel-tired wheels, some of which have an average life of over 300,000 miles, and in the end prove more economical than the cheaper cast-iron.

The most important step yet aimed at is the establishment of a

standard freight-car-truck. Under the guidance of Mr. M. N. Forney, efforts have been made for some years to secure this result; and, with the active concurrence of many experienced builders, there is a prospect of the design, Fig. 2, being adopted. This truck has a wheel-base of 5 feet. Its framework is of the so-called diamond type, the name being taken from the shape of the sides. The car body is loosely connected to it by a centre-pin held vertically in the middle of the bolster, on which it can turn a complete circle. The bolster itself rests on springs, and may be either rigid laterally, or have a swing-motion. Diversity of opinion exists as to the value of this motion for freight-cars, but it

FIG. 2.



STANDARD FREIGHT-CAR TRUCK.

is universal for passenger-cars (Plate 2, Fig. 2), and it is estimated that one-half of the freight-cars have it. In passenger-car trucks the bolster and spring-plate are carried on side-equalizing bars, which rest on the axle-boxes, and further lessen shocks from the road-bed by additional springs. In principle all the trucks, whether for cars or engines, are the same, and aim at giving the greatest amount of ease of motion compatible with safety. This flexibility, with the short rigid wheel-base of 5 feet, is characteristic of the American freight-car in contrast with the absence of flexibility and long rigid wheel-base of 8 or 9 feet in an English goods-wagon, and these qualities enable the former to work well on

rough roads with sharp curves that the latter could not run upon.

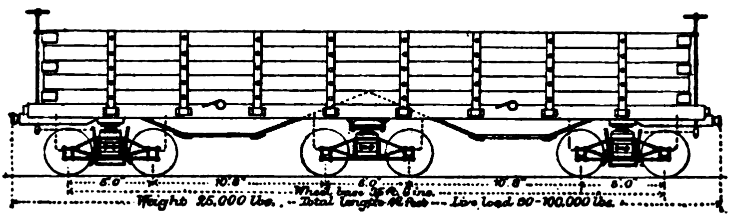
In Plate 2, Figs. 3 and 4, are given respectively the latest designs of Mr. Ely for the Pennsylvania Railroad (4 feet 8½ inches gauge), and of Mr. Congden for the Union Pacific narrow-gauge (3 feet). The former is for cars to carry 60,000 lbs. It is built entirely of iron, Mr. Ely being of opinion that the limits of safe strain for wood have been passed. The Union Pacific narrow-gauge truck is to carry cars with 40,000 lbs. burden, or the same as the standard-gauge car-trucks of the same company. Its wheel-base is 4½ feet, or 6 inches less than that of the standard truck. With the exception of the bolster and spring-plate, which are of wood, all the parts of the standard truck are of iron; and it will be possible to substitute iron, as in the Pennsylvania truck, for the wood. In this case every separate part may be reproduced with the utmost accuracy; and, if a standard of strength and quality of metal can be secured, there will be a complete interchangeability of the different items, and a consequent reduction of cost both in the material and in the labour of putting the parts together.

It is impossible to exaggerate the extreme importance of this in an economical direction. The truck itself is less a design than the product of evolution from a myriad of variations of design worked out in millions of examples. It is the crystallized embodiment of experience under a multiplicity of requirements; and, once finally chosen, it is likely to remain for the next quarter of a century without change except in improvements of detail. It is estimated that about 800,000 freight-cars are in use in the United States alone. Delays and complications arise through want of uniformity in the size and strength of the parts in making repairs, and the immense advantage to accrue from a universal standard must bring about a very rapid conversion of the whole to the new pattern. It is obvious that the facility of reproduction of each part by special machinery on such a scale must minimize the cost so much that even if it were possible to work out a better design (unless an entirely new departure), the present one must dominate and supersede all others, exactly as the standard gauge of 4 feet 8½ inches has driven out others; and wherever competition is open in other countries the proved qualities of small cost and great efficiency must give it the preference over all rivals. In the Author's opinion this standard freight-car-truck, having established itself by the survival of the fittest, is likely to become the initial point and unit of reference for ordinary railway-work in new countries in the future, and it remains for manufacturers

to study how far they can give the highest excellence of quality to each part at the least cost.

Though designed to carry 40,000 lbs. in each car, it will probably be often burdened to twice that amount, as the tendency is unmistakable, and cannot be restrained, to increase the proportion of paying-load to dead-load in the cars. The only limit on each line is the power of the bridges to sustain the trains, or rather the increased weight of the engines now made. As a rule only two trucks are used to each car, but latterly a third truck has been introduced under the centre of the car body (Fig. 3). This gives support just where the trussed framework of the bodies is weakest, owing to the door-aperture being there. Plate 2, Figs. 7 and 8, give drawings of late designs of freight-cars in general use. The hopper gondola-car of the Pennsylvania Railroad is designed to carry 60,000 lbs., and weighs only 19,800 lbs. By dispensing with the hopper it becomes a plain gondola-car; and if the sides are removed it is a common flat-car. The box-car of the West Shore Railroad is heavier than usually designed, as it weighs over 24,000 lbs. to carry 50,000 lbs. The stock-car and refrigerator-car for meat and garden products are similar to this in structure, but have special fittings.

FIG. 3.



THREE-TRUCK FREIGHT-CAR.

The Author does not consider that any claim can be made for exceptional economy in the conveyance of passengers in America, nor is it more efficient than in England. An ordinary passenger-car and an immigrant-car of the latest type are shown in Plate 2, Figs. 5 and 6. The wheel-base ranges up to 7 feet for four-wheel trucks; but larger cars have six-wheel trucks with over 10-feet wheel-base. The usual length of car is from 50 to 60 feet, carrying 50 to 70 passengers in ordinary cars, with a total load of 40,000 to 60,000 lbs.; but some parlour-cars take only 20 to 30 persons, with a total load of over 80,000 lbs. Special accommodation is given, but, as economy is the object of study, that does not enter into

consideration. The peculiarities of the cars, with end-platforms and steps, through communication and accessible conveniences, are well known.

All rolling-stock is connected with central couplers, and attempts are being made to secure uniformity in these for all the lines, but up to the present little has been done, though standard draw-bars and links have been proposed. Committees have been formed to deliberate on the best kind of automatic couplings; but as there are from 3,000 to 4,000 of these offered, a decision seems difficult. In the meantime the Miller and the Janney, with combinations of both, are extensively used for passenger-cars, and are recommended for freight-cars. Standard switches and frogs are strongly advocated.

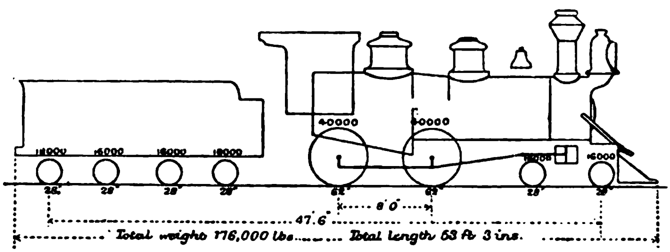
The practice is becoming general, and opinion is universal in favour of automatic brakes being applied to freight-cars, preference being given to separate application on every wheel. The Westinghouse air-brake is extensively used, but its expense of about £10 per car, besides the cost of the engine on the locomotive, is against its universal adoption, though its efficiency is well known. Brakes costing £3 per car, and others £2 per car, are advocated, but they have not proved efficient enough to secure wide support.

A separate Paper would be necessary to discuss the differences between English and American locomotives, but as the sole essential difference, if it can be said still to exist, is the universal use of bogie-trucks with the shortest possible rigid wheel-base for the drivers in the latter, so far as the economy of construction and working of roads is affected, a mere enumeration of the others will suffice at present. In the American locomotive, Plate 3, Fig. 1, the solid bar-frame is retained, generally forged throughout, and it is rigidly connected to the boiler, forming with this a complete truss. This is in marked contrast to the English plate-frame, complete in itself, connected comparatively loosely by a few bolts to the boiler, which rests upon it as on a cradle. Opponents of the latter allege that there are not sufficient diagonals or lateral stiffness to prevent deformation under side-strains, and trace the breaking of crank-axles and of coupling-rods to this cause; while it is certain that frequent total failures of the American frames occur, particularly at the welds. Outside cylinders are universal in American practice, with steel fire-boxes, cast-iron wheels, and equalizing bars for all the wheels. In engines with long wheel-base alternate sets of wheels have broad treads without flanges, and are called blanks. Minor differences from English practice, such as the cow-catcher,

the spark-arrester on the smoke-stack, the enormous lantern, the bell, and the commodious cab for the attendants, with a more ornate general appearance, are to be observed in American locomotives.

Of late years in the best English practice the principle of flexible wheel-base in locomotives has been adopted, so far that the American bogie, or the Adams's bogie, or some equivalent like Mr. Webb's radial axle-boxes, is in general use; while on some lines equalizing bars are also used. The permanent way of English railways does not necessitate the practice being carried so far as in America; but having admitted the desirability of a flexible wheel-base, there is no reason why manufacturers of locomotives should not push it to the fullest extent of which it is capable in preparing engines for economical railways abroad. No English engineer will admit that in excellence of material or

FIG. 4.



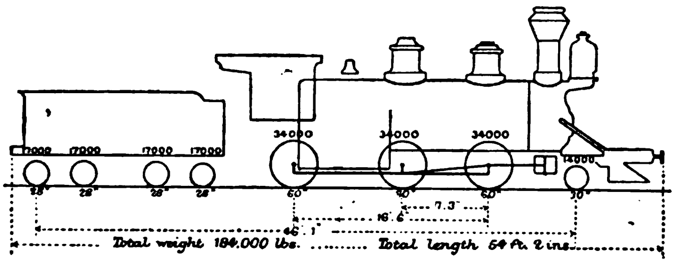
AMERICAN.

workmanship, or skill in design, the locomotives made in this country are behind any in the world; but it is none the less obvious that unless they are adapted for rough and cheap roads, and made capable of working easily upon them, they will be driven out of the field by competitors fulfilling those requirements.

Sketches in outline to a scale of $\frac{1}{200}$ are given, with a few data of late practice in American locomotives, showing the principal types in use. Engines with a single pair of drivers are used, but only rarely; the ordinary passenger- and light goods-traffic being mostly worked by the so-called "American" engine (Fig. 4), with four drivers coupled, and a four-wheel bogie. The Baldwin Locomotive Works, which may be taken to represent the best American practice, make this engine with wheels up to $5\frac{1}{2}$ feet diameter, and a rigid base of $8\frac{1}{2}$ feet, the weight of ordinary sizes in working order being from 56,000 to 80,000 lbs. The "Mogul" type has six drivers coupled, the central pair blank, usually from

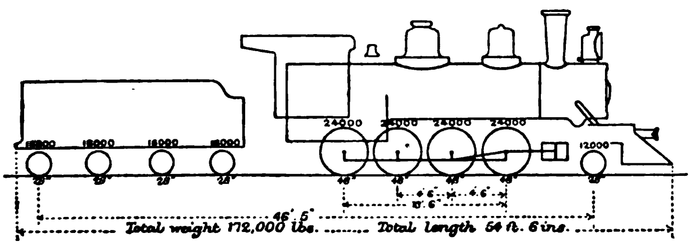
4 to 5 feet in diameter, and 14 to 15 feet length of base; the weight usually ranges from 40,000 to 90,000 lbs. in working order. The one shown in Fig. 5 is exceptionally large and heavy, and was made for the Philadelphia and Reading Railroad. It has a pony-truck of two wheels, with a radius-bar. The Mogul is used for freight trains on ordinary gradients. So-called "Mixed" freight-engines, or Moguls with four-wheeled trucks, and a somewhat shorter driver-base, are also used; and six-coupled drivers without bogies are used as "Pushers" on the Pennsylvania

FIG. 5.



MOGUL.

FIG. 6.

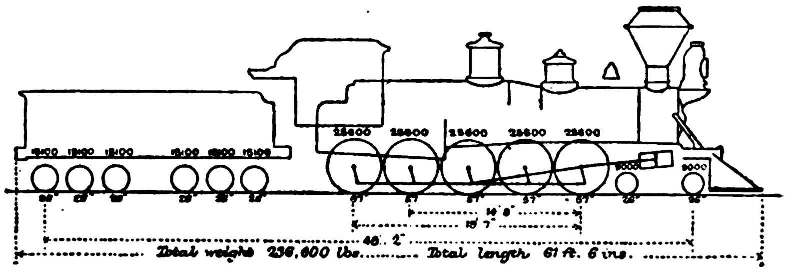


CONSOLIDATION.

Railroad, in rear of heavy trains going up steep gradients. "Consolidation" engines of eight coupled drivers (Fig. 6) are used as "Headers" on mountain lines and undulating country. The wheels usually range, on standard-gauge roads, about 48 or 50 inches in diameter, with not over 15 feet rigid base, the central pairs being broad blanks. From 85 to 90 per cent. of the weight, which usually ranges on standard gauge from 80,000 to 120,000 lbs. in working order, is thrown on the drivers. Of late years the "Decapod" (Fig. 7), or ten-wheel coupled drivers, and bogie-truck on two or four wheels, has been developed both for narrow-gauge

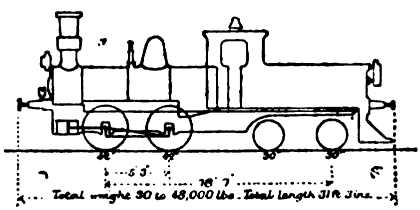
roads of 3 feet and for standard-gauge roads.[1] The figures given in the sketch are those of "El Gobernador," made for the Southern Pacific Railroad, the largest engine in the world, where it is used for taking 500-ton trains up grades of 116 feet to the mile. The last sketch (Fig. 8) is of the "Forney" type, where the tender is carried in the same framework with the engine, on a four-wheel bogie, and four coupled drivers of short base. This is run with the chimney in the rear. The engine is much used on suburban lines, and on the Elevated Railroad in New York, taking trains round curves of 90-feet radius, and giving much satisfaction. Its weight is 32,000 to 36,000 lbs.

Fig. 7.



Decapod.

Fig. 8.



Forney.

Contrary to what might be expected from the ingenuity and adaptiveness of the Americans, the tendency in railway construction and operation is less in the development of new principles and designs, in order to secure greater economy and efficiency, than in improving and perfecting the older types and practices, and bringing them to standard forms for universal adoption. So that, in wishing to benefit by the results attained, it will be sufficient to examine the extreme limits reached, and to study the latest modern practice.

[1] The rear pair of wheels is allowed to move laterally on curves.

Thus, even the most economical roads must use the ordinary freight-car of 20,000 lbs. weight, and load it to the limit allowed by the bridging. In designing new roads with the utmost attention to economy, the best practice tends to make the bridgework strong enough to carry a train of locomotives such as are to be generally used on the roads; and, following this out to its legitimate conclusion, the freight-cars should be loaded to their utmost capacity to secure the greatest proportion of paying-load to dead-load within the limit of equal weight per lineal foot of cars for weight per lineal foot of locomotive. This is already being approximated to on the best lines using the heaviest engines. On the new road now in course of construction in South Pennsylvania, the bridges are designed to carry a train with two coupled "Consolidation" engines, each weighing with tender 171,000 lbs., with 24,000 lbs. on each pair of drivers; or one "Decapod" of 195,000 lbs. with tender. The iron bridgework of the Canadian Pacific, as designed by Mr. Shaler Smith, is to carry a train of locomotives, of "Consolidation" type, with 21,260 lbs. on each pair of drivers; and a total weight with the tender of 166,820 lbs. on a length of 56½ feet, or nearly 3,000 lbs. per lineal foot. The Atchison Topeka Railroad bridgework has been designed by Mr. A. A. Robinson to carry a train of "Consolidation" engines, with 24,500 lbs. on each pair of drivers, or 160,000 lbs. on a length of 57½ feet. The Pennsylvania Railroad Company requires similar tests for its bridges, where two "Consolidation" engines, followed by a train weighing 3,000 lbs. per lineal foot, are to be carried according to Mr. Wilson's designs. And in the general practice of the best makers and designers, weights ranging from 3,000 lbs. per lineal foot for first-class bridges to 2,000 lbs. per lineal foot for lighter lines, following two of the heaviest engines employed on the road, are used for calculating the strains. If the present freight-cars of 20,000 lbs. weight are loaded to 70,000 and 80,000 lbs., as is sometimes done on the Pennsylvania and other first-class roads, this limit is nearly reached already with 36 or 37 feet cars; and with twelve-wheel, centre-trucked cars, where a still higher proportion of paying-load is sought for, it will soon be reached.

Already trains averaging one hundred loaded cars are taken over the Pennsylvania Railroad. On steep gradients they are conveyed by two "Consolidation" headers, and one pusher. Probably they take some 3,000 tons of paying-load per trip. It is in this direction of enormous paying train-loads, carried on a minimum of dead weight, that economy is sought on the trunk-lines in the

heavy east-and-west traffic, and the best authorities look forward to a steady though gradual increase in rail-weight and in paying-load on twelve-wheeled cars on all these lines.

Up to the present steel rails weighing 82 lbs. per yard are the heaviest used in America, a portion of the New York Central Railroad having been laid with them. As the cross-ties or sleepers are invariably closer together in American than in English practice,[1] this implies a greater strength of way than the same weight in England. The rails are mostly 30 feet long, and at least sixteen cross-ties of 8 feet to 9 feet in length, 8 inches in width, and 6 to 7 inches in depth, are generally laid to each length on the standard gauge. Oak or other hard wood is principally used, and this averages eight to ten years' life. The flat foot of the rail is from 4 inches to 4½ inches broad, so that, with the larger number of sleepers, the bearing-surface is much greater on the wood than in English practice; and this again has a broader spread on the earth, securing more elasticity to the roadway.[2] Where timber is cheap, and good ballast scarce, the number of cross-ties is increased. The principal trunk-lines have been using steel rails weighing 65 to 67 lbs. per yard, a few having rails of 69 lbs., and, when traffic is not great, of 60 and 61 lbs. per yard; while for branches and lighter lines rails of 55 and 56 lbs. are used, standard-gauge roads rarely having anything lighter than this. Narrow-gauge roads of 3 feet width, like the Denver and Rio Grande, are supplied with rails of 40 lbs. There is a decided set of opinion amongst the best American engineers against light rails either for narrow-gauge, or so-called light railways. Economy is to be sought for elsewhere than in either rolling-stock or permanent-way, meaning by this the rails and sleepers. An extensive prejudice exists against gauges less than the standard, which experience has proved to be the most suitable for all traffic except in extremely difficult mountain regions.

It remains to seek for the economy of construction of American railways in the small outlay in first cost of grading, alignment, and heavy works, and in the gradual adaptation of the roads to the traffic requirements. A glance at the hypsometrical map of the American continent, and the network of lines running over every

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[1] From 18 to 23 inches apart in American against 33 to 36 inches apart from centre to centre in English, or from two-thirds to half the distance.

[2] The bearing-surface of the rails on the sleepers averages (2,800 × 8 inches × 4¼ inches =) 1,322 square feet; and of the sleepers on the ballast (2,800 × 8 feet × 8 inches =) 15,000 square feet per mile.

part of the United States, shows that no exceptional facilities have been naturally offered for the roads; and a closer examination of what has actually been done proves that extraordinary difficulties have been surmounted by first-class lines and light lines alike.

The United States is divided physically into two immense plateaus of equal extent by the 99°th meridian, that to the east rising from sea-level to an average elevation of less than 1,000 feet, while the western one rises to a mean height of over 5,000 feet above the sea. The latter forms the base of the Cordilleras, which is broken up into the minor ranges of the Cascade, the Wasatch and the Rocky Mountains, which last spread out in Colorado, in a table-land from 5,000 to 10,000 feet high, with peaks rising to over 14,000 feet, and passes from 10,000 to 12,000 feet above the sea. Here are found the narrow 3-feet gauge roads of the Denver and Rio Grande, and of the Union Pacific Railroads. Both to the north and the south the ranges trend lower to where they are crossed by the great transcontinental or Pacific roads. The descent from the western plateau to the eastern is generally easy, though considerable irregularities are met in the foot-hills where branches of the great Granger or north-western roads penetrate. These railways, which have been much extended of late years, are in their later examples thoroughly representative of the best and most economical system of American construction, and a short account will be given of one of them.

If the whole eastern plateau were sunk 1,000 feet, little of it would remain above sea-level but a series of islands running north-east and south-west where the Appalachian range is now. This at present has a few peaks over 6,000 feet high to the extreme north and south; but its ridge is much lower, being crossed by the Baltimore and Ohio Railroad at a summit elevation of 2,706 feet, to which it ascends by continuous grades of 1 in 45, over 11 miles long on the one side and nearly 17 miles on the other, combined with curves of 600-feet radius, with other portions still more severe. The Pennsylvania Railroad crosses the same range at an elevation of about 2,160 feet, with gradients originally of 1 in 37 and 1 in 49, combined with curves of 345-feet radius. Regrading and realignment has much improved this part of the line, over which very heavy freight-trains are regularly worked. The Erie Railroad was originally laid out with extreme care to secure the best gradients and curves over the whole line; to get over a summit of 1,374 feet, heavy expenses were incurred in making the maximum gradient 1 in 88. The policy of this has been challenged,

as the cost averaged £44,440 per mile, and the line has been in a chronic state of bankruptcy ever since.

The New York Central Railroad has a maximum gradient of 1 in 56, with sharp curvatures; but its late rival, the West Shore Railway, which like it follows the Hudson river, and has a low summit to cross, secured west-going gradients of 1 in 264, and east-going ones of 1 in 176, with curves of 1,146, 1,274 and 1,432-feet radius, but at the cost of bankruptcy and absorption by its rival.

On other important lines in the same regions steep gradients and sharp curves are freely used. The Lehigh Valley Railroad has maximum gradients of 1 in 42, and one uniform slope 12 miles long of 1 in 55, of which only 2 miles are straight; curves of 574 and 718-feet radius being combined with it. Trains weighing 400 tons are run up this slope at the rate of 12 miles an hour. On the Cumberland and Pennsylvania Railroad gradients of 1 in 34 combined with 300-feet curves are regularly worked with 160-ton trains. There are altogether about nine trunk-lines connecting the Atlantic sea-board with the interior, and on over 14,000 miles of these, far more than half the traffic of the United States is conveyed, and half the revenue earned; on most of these, severe inclines and sharp curves have been profitably worked for many years owing to the facilities offered for economical construction by the use of the short wheel-base and flexible connections of the bogie-truck. On going completely through the statistics of railroads given in the United States Census Report of 1880, there is found hardly a line of importance which does not show a free use of gradients of 1 in 100 and above it.

The Pacific roads all have steep gradients freely where required. The Southern Pacific has several miles with 1 in 46; the Union Pacific 1 in 59; the Central 1 in 46 or 116 feet per mile, which is also used by the Canadian Pacific in one continuous slope 18 miles long, with frequent curves of 574-feet radius. On the Switch back of the Atchison Topeka and Santa Fé Railroad, where it crosses the Sangre-di-Christo range, trains weighing 200 tons, exclusive of engines, were run at the rate of 6 miles an hour up a gradient of 1 in 16·6 combined with curves of 359-feet radius. So far as the first-class and trunk-roads are concerned it therefore appears that a maximum curve of 1 per cent. may be ordinarily resorted to, while greater difficulties are overcome by gradients even higher than 2 per cent.

For the most economical railways of standard-gauge the steepest gradients are resorted to, and in this the American practice agrees

with the theoretical studies of Mr. de Freycinet, who in his work on Economical gradients,[1] came to the conclusion that standard-gauge lines of moderate importance, when crossing rolling country, would reach the most economical gradient in 4 per cent.[2]; but for slightly uneven and partly plain land 1·8 per cent. is the most economical gradient. The most eminent and experienced American engineers, however, attach more importance to the free use of curvature, even of great sharpness, in attaining economical construction for cheap lines. A Table is given below of curves actually employed in 4 feet 8½ inches roads:—

	Feet radius.
New York, New Haven, and Hartford	410
Lehigh and Susquehanna	383 320 309
Baltimore and Ohio	400 375 300
Virginia Central	300 238
Pittsburgh, Fort Wayne and Chicago	246
Brooklyn, Bath and Coney Island	55 to 125
Metropolitan Elevated	90 and 103·5
New York „	46, 100, 125, and 150

More than eight hundred trains run daily over the last two lines, on which there are also gradients of 1 in 50.

For narrow-gauge lines no finer specimens can anywhere be found than in Colorado, where the Denver and Rio Grande and the Union Pacific branch-lines climb mountains and traverse cañons with precipitous rocky sides with the utmost boldness and success. It is impossible to do justice to the engineering skill shown on them in a short Paper; but it may be mentioned that the former line has opened out the wild but rich mining regions with 1,650 miles of 3-feet gauge line in the last few years; while the other is still spreading many hundred miles of the same gauge through similar country. Plate 4, Fig. 2, gives a sketch of the principal heavy gradients of the Denver and Rio Grande Railway, from which it will be seen that while there is one gradient of 1 in 22 there are several long ones of 1 in 25,

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[1] Les pentes economiques.

[2] The Mexican Railway has many miles on 4 per cent. gradients, and the Peruvian Railway has nearly 50 of the same in a continuous line on the standard-gauge lines. Mr. Wellington says that a reduction to 300-feet radius brings the cost enormously below what a 600-feet radius would give in very rough country; and for ordinary undulating country curves of 478- to 573-feet radius are found expedient.

combined with curves of 240-feet radius; and in one case of 193 feet. When the Author passed over the line in 1884, however, some of the more severe curves were being re-laid with radii of 383 feet as a maximum. Passenger-trains are run over these passes, sometimes of seven or more cars, with double-headers of one Mogul and one Consolidation engine; but freight-trains, with maximum loads of 246,000 lbs., are taken over by three Consolidation engines, of 16- by 20-inches cylinders, each engine weighing 70,000 lbs. On inquiring regarding the relative merits of headers and pushers on this line, the Author was told, "On our heavy grades and sharp curves we never put an engine behind as a pusher, as, in case of accident, the damage to property would be doubly increased by the pusher going through the hind end and setting it on fire, &c., as on a mountain road like ours short stops are very frequent on account of rock and land slides falling on the track. We can generally get through an accident to a passenger train, ditching the engine, baggage, and mail-cars, leaving the coaches on the rails with the occupants somewhat shaken up, but none the worse for their experience; whereas if there were a pusher on, the passengers in the rear coaches would, in nine cases out of ten, be crushed or scalded." The Author went over some 1,200 miles of the railway, and in the more dangerous parts of the main-line found the utmost precaution taken, patrollers watching it incessantly and meeting each other over short lengths.

One of the finest pieces of alignment visited by the Author was on the Union Pacific Railway, on the narrow-gauge line between Georgetown and Graymount (Plate 4, Fig. 1), where the bed of a narrow valley rose more rapidly than the maximum gradient allowed on the line and the ascent is made in a continuous loop, returning over the line by a high bridge as shown in drawings.[1] Curves of 193-, 206-, 240-, and 280-feet radius are freely used in accordance with the best American practice.[2]

The Chicago, Milwaukee, and St. Paul Railway Company owns and operates nearly 5,000 miles of line, and is thus the largest private railway concern in the world. It has neighbouring rivals, however, in the Chicago and North-Western Railway, and the

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[1] Kindly supplied by Mr. Blinkensderfer, Chief Engineer.

[2] This invariably allows compensation when the curve falls on a gradient by lessening the inclination as the sharpness of the curve increases. Some difference of opinion exists amongst the authorities as to the amount of reduction required, but the average given is 0·05 per 100-feet per degree of curvature. This means

Chicago, Burlington, and Quincy Railroad, both of which nearly equal it in mileage and in revenue, and cater for the same business. In 1883 it carried 4,591,000 passengers a total of 235,579,000 miles, and its freight traffic was 1,177,000,000 ton-miles; the rates being 1·26*d.* and 0·695*d.* per passenger-mile and per ton-mile. Its equipment consisted of 657 locomotives, about 500 passenger and other coaches, and 19,734 freight-cars, &c. It owns coal mines, from which it takes some 500,000 tons annually, and is very completely furnished with most expensive terminal facilities in the great cities, and with several workshops (Plate 4, Figs. 4 and 5), warehouses, elevators, and docks. Steel rails are being rapidly substituted for iron where these still exist. The Author went over many hundred miles of the line, visiting the principal stations, workshops, bridges, &c. (Plate 3, Figs. 7, 8, 9, 10, and 11), on the invitation of the Chief Engineer, Mr. Whittemore, then President of the American Society of Civil Engineers, of whom he asked for detailed information regarding its construction.

Mr. Whittemore, who has been in charge of the line for forty years, replied as follows, November 25th, 1884:—Regarding "the American plan of constructing railways at a cost that would be remunerative in a new country, and thus make them agents of civilization and a profit to the nation, by necessity we in America build and operate railways with safety (and on our line certainly with profit), that cost, fully equipped for the required traffic, not to exceed £3,000 to £4,000 per mile. To do this we use often sharp curves, steep inclines, and structures of wood. In the first instance our lines are located with a view of cheap construction.

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the angle subtended at the centre of the curve by a chord of 100 feet, the universal method of expressing curvature in America.

	1°	5°	8°	10°	12°	14°	16°	18°	20°
radius	5,730 ft.	1,146 ft.	717 ft.	574 ft.	478 ft.	410 ft.	359 ft.	320 ft.	288 ft.

The practice varies, however, and Mr. A. A. Robinson, who has had great experience on steep gradients, gives as follows:—

			Per 100 feet per degree.
Rate of maximum grade .	0 to 1 in 166·0	compensation	0·06
" " " .	1 in 166 " 1 " 62·5	"	0·05
" " " .	1 " 62·5 " 1 " 33·3	"	0·04

Mr. Blinkensderfer gives 0·03 to 0·07 in the same limits; while Mr. Wellington allows 0·06 on all maximum curves. The practice also of widening the gauge on curves varies much. Some engineers allow only the same play of ½ inch, that is given on straight lines; while others increase it ½ inch and more on curves. But opinion is unanimous in requiring a tangent between reverse curves, and sharp curves are eased off at both ends. In some cases also gradients are eased at the approaches.

We do not suppose that the line will be called upon to pass over from four to six trains per day, counting both directions, and from the income of these loads our revenue must come. In the course of time, as the revenue of the country increases, and as business demands, the lines are gradually improved, inclines lowered, curves made easier, permanent structures introduced suited to the economic demands of increased traffic, and at this point we find ourselves glad to make use of the experience of our English brethren. Thus it is estimated that could the Pennsylvania Railroad (one of our standards of excellence) cut out 1 mile of its road at an expense of £100,000 it would be policy now to do so; yet if in its inception this had been attempted, bankruptcy would have followed. We of America have much to learn and copy from England as to the construction of the perfect railway, yet should we be guided entirely by them in all our work of this character, our progress in the new regions would be at once arrested. The history of our line is peculiar. An organization commenced with but 45 miles, and by consolidation with a purchase of bankrupt lines, grew into large proportions. In 1878 our funded debt, all classes of stock and bonds, amounted to about £7,600 per mile. Since then we have constructed the following mileage—

1878 . . .	226 miles.	1882 . . .	219 miles.
1879 . . .	155 „	1883 . . .	205 „
1880 . . .	326 „	1884	40 „
1881 . . .	442 „		
	Total		1,613

all standard gauge, at a cost, equipped for business, of from £3,000 to £4,000 per mile, so that now our funded debt is, I believe, slightly less than £6,000 per mile on the 4,800 miles owned and operated by the company. At least three-fourths of the distance of 1,600 miles were into unsettled country and in advance of civilization, which however pushed forward within one year after building, and all the lines paid expenses of operation within one year after completion. As the demands of remunerative business warrant, permanent improvements in the railway are made. Whenever 40 per cent. of the gross earnings will pay interest of funded debts, then generally the balance left over, after paying operation, is expended in such improvements. In the first instance, all our bridges are constructed of wood. In the 1,600 miles of line built since 1877 we probably did not have to exceed 3,000 cubic yards of masonry. The earthwork required in building will probably average about 15,000 cubic yards per mile.

The timber-work for pile and trestle-bridges and culverts, exclusive of truss-bridging, will be about 1 foot board-measure to a cubic yard of earthwork. This does not include piles, which are paid for by the lineal foot. Truss-bridging amounts to about one 100-foot-span to each 10 miles. On our entire line we have about 94 miles of all kinds of bridging (pile, trestle and truss), or 2 per cent. of its entire length. Our timber-work costs about £6 per B. M. Piles driven about 30 cents per lineal foot, and truss-bridging, 100-feet spans, £5 5*s.* per foot, and 150-feet spans, £6 15*s.* per foot. At present we lay no iron rails. Trunk lines have 67 lbs. steel per yard. Minor lines have 60 lbs., and light-traffic lines 56 lbs. steel per yard. Cross-ties 6 inches by 7 inches, and 6 inches by 8 inches, 8 feet long, about 2,800 per mile. We now purchase only angle fish-plates 37 to 40 lbs. per pair, and spikes ½ lb. each. Our standard wooden bridges, pile, trestle and truss, etc., are shown (Plate 3, Figs. 4, 5, and 6). The average life of our wooden culverts and pile- and trestle-bridges is from eight to ten years, and truss-bridges nine to eleven years. In new structures we make the limit in tension 10,000 lbs., but in hanger-bolts liable to shock bring this down to from 4,000 to 5,000 lbs."

Replying to an inquiry whether the link-and-pin bridges in iron and steel in universal use in America would not allow designs to be prepared so as to admit of additional members being added as the freight tonnage increased, he says: "I would not like to attempt to design a bridge with provision for additional strength, as you propose. There would not be so much difficulty in providing for additional tension-members as for those of compression. I take it that it would be better to give the strength in the first instance."[1]

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[1] The Author laid this problem before other distinguished bridge engineers, that is: Could not the American iron bridge be so designed for economical railways as to allow of its being strengthened afterwards by additional members for increased traffic? This would dispense with the costly process of replacing light and temporary wooden bridges after eight or ten years of service, and be especially useful in countries where timber is not cheap. The replies were generally unfavourable. Mr. C. S. Maurice, of the Union Bridge Company, thus writes: "I can answer your question in a general way, by saying that iron bridges have not been built or designed in this country with this end in view. The problem which you raise has been met in practice by the construction of cheap wooden bridges known as 'Howe Trusses,' having a life of six to ten years on new lines of light traffic, and replacing them with iron bridges of standard proportions when the development of business would warrant the outlay. In some instances iron bridges which were deficient in section have been remodelled and strengthened so as to bring them up to present requirements, and in other cases bridges which were insufficient for the traffic of

Mr. Whittemore has very kindly given several drawings of works connected with the line, including the newly-designed workshops near Milwaukee (Plate 4, Figs. 3 and 6) and other places. The managers of these large railway-systems find it preferable to distribute a number of shops over the line to having them concentrated. Every branch of construction of cars and locomotives, as well as repairs, is carried on in them; but the system is general in the United States of having, as far as possible, separate articles made in special factories to standard forms and strengths, and this is found to be at once cheaper and better than each place making everything for itself. Mr. Whittemore, in sending the plans, says: "I wish to say that we see many of our faults, and wherein we can learn much from our English brethren. Before designing our shops we sent one of our best men (an Englishman) to England, and I personally examined the best shops in this country, and from the knowledge thus gained evolved ours. I could not prevail on our people to make use of cranes to the extent used in England, and in this we are at fault." For comparison, the new shops of the Chicago, Burlington and Quincy Railroad at Burlington are shown, as designed by Mr. Rhodes. The great length of engines with tenders necessitates enormous turn-tables and beds, for which 65 feet is becoming requisite.

On the Chicago and Milwaukee principal lines, or on from two-thirds to three-fourths of the system, the stations average 3 to 4 miles apart, and on the rest about 7 miles apart. There sidings are laid for passing trains, when, as in most cases, it is a single track.[1] On the Chicago and North-Western Railway the propor-

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a 'main line' have been utilized on 'branches,' where only light rolling-stock was used. In the former case, however, no provision was made in the original designs for increasing the sections, and the change has been made by substituting entirely new compression-members and floor-systems. It would be a very simple matter to design our pin-bridges so that additional *tension-members*—lower chords and diagonals—could be added at any time, but I hardly think it could be practicable to carry out the same idea with the *compressive-members* and cross-floor beams."—Athens, Penn., Dec. 28th, 1884.

[1] The problem has been raised: What is the maximum capacity of a single track? To this much attention has been devoted, but the numerous varying elements make it impossible to give a general answer of value. Mr. Thompson, of the New York, Pennsylvania and Ohio Railroad, deduced that ("Railway Gazette," 1884, p. 43) for trains running an average of 20 miles an hour, the most economical speed for freight, the maximum is reached with stations and passing-places 3·7 miles apart, when, with an allowance of six minutes detention for each train crossed, and eight minutes extra for each passenger-train passed, it is found that the limit is reached when the time of detention equals that of running

tion of side-track is 9 per cent., and on an average there are twelve trains both ways daily; the Cleveland, Columbus, Cincinnati, and Indianapolis Railway, with 30 per cent. of side-track, accommodates twenty-four trains daily; the New York, Pennsylvania and Ohio Railroad, with 35 per cent. of side-track, thirty trains both ways. The Pennsylvania, with 70 per cent. of side-track, passes fifty-one trains, passenger and freight, over its trunk lines both ways daily; and the Erie, with forty-five trains, has 90 per cent. of side-track.

As the result of his observations on several thousand miles of North American railways of all classes, from communications with distinguished American engineers, as well as from the study of papers published by technical societies and periodicals concerned with the subject, the Author has come to the following conclusions: 1st. That there is no difference in the principles underlying the American practice in the location of light railways and that of the most expensive and perfect railway for heavy traffic; and that while the former is to be looked upon as an imperfect stage of development of the latter, due consideration is usually given and provision made for the growth and improvement of the line to a better condition as traffic increases, with the least possible fundamental alteration in the line or its belongings. The highest engineering skill is as much or more required in laying out a cheap and light line as a heavy line. 2nd. The latest and best American practice rejects the use of very light rails and permanent way for an economical railway. It must be prepared for the ordinary passenger and freight cars of the country to pass over it, the only difference being that lighter loads would be carried on the light line. To fix the ideas, without attaching precise value to the figures, it might be expressed by saying that whilst 3,000 lbs. per lineal foot of train appears to be the maximum load of a freight-train on a heavy road at present, 2,000 lbs. per lineal foot is the limit of the light railway; and the bridge-work would be calculated for these loads respectively. Steel rails, weighing not less than 55 lbs. per yard, with rigid connections (sufficiently

in the twenty-four hours, which gives sixty trains per day both ways. For fifty trains and over, the track should be doubled between the termini and the next stations. In practice it is found that grades limit the number of cars run in a train, so that, if forty loaded cars be the ordinary number on the level, only twenty are taken over undulating country by a single engine. Actually on Mr. Thompson's division, 98 miles in length, the standard engine takes nineteen cars, the Mogul twenty-three cars, and the Consolidation thirty-three cars each per train.

long to rest on three sleepers), and sleepers, not less than two thousand eight hundred per mile, with 15,000 square feet of bearing surface on the ballast, should be used. 3rd. The nature and amount of traffic to be provided for being fixed, a variety of opinion and practice appears to exist as to the mode of working it. Thus some advocate light engines and a larger number of trains in order to facilitate and encourage the growth of traffic, while others prefer heavier engines and fewer trains, with greater loads as being the more economical. In practice matters are settled very much by the conditions to be fulfilled. In the Far-West, where distances to be traversed are great and traffic is as yet small, sometimes one or two trains only are run each way per day; and here are found some of the heaviest engines in use in the country both on standard- and narrow-gauge lines, with trains loaded to their fullest capacity.[1] While in the newer countries of the Mid-West, where settlers are more numerous and movements brisker, it is good policy to run light trains oftener. The question is of importance in determining the weight and the character of the locomotives which with the previous data fix the conditions of the alignment. 4th. The practical recommendations of the alignment may be thus briefly summed up:—When no extra cost is involved by it, the same grading and curvature that could be given to the best railway the country admits of should be used

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[1] Professor A. Frank draws the conclusion from numerous experiments in Europe by Wöhler in 1879 and himself in 1882 (Minutes of Proceedings Inst. C.E. vol. lxxv. p. 348), that it is desirable on economical grounds to give to each engine the heaviest train it can draw, not only because it is better employed, but because the useful effect increases with the work done. The engine must not be overloaded so as to cause too much priming, &c. Again, a succession of rising and falling gradients have a very small effect on the work done, provided that the speed in descending has not to be checked by brakes. The load to be put on an engine must be calculated with reference to the steepest gradient it has to surmount, and the maximum resistance it may encounter on that gradient. It has been proved that the useful effect is practically independent of the speed, and this result has important consequences. As the speed diminishes the resistance of the air diminishes in a much higher proportion, and the traction power at the same time increases. Hence, lowering the speed is very effective in overcoming great resistances, but a limit is set to this by the adhesive force between tires and rails.

It would thus appear that independent of questions of policy, the most economical mode of operation would be with the heaviest engines the line would bear, likely to be required within the first few years, and worked up to the fullest capacity with the fewest number of trains, and this actually seems to be the method employed for freight-transport- and mixed-trains in the Far-West of North America.

for the economical line. In undulating country the surface line should be approximated to, and all undulations of not more than 13 feet may be adopted with ordinary gradients without incurring any expense to avoid them.[1] Above that height an expenditure of from £20 to £100 for each vertical foot in height may be incurred to avoid the undulation. Where it is necessary to resort to stiff gradients they should be eased off at both ends; and for speeds of 15 to 20 miles an hour the introduction of breaks in the gradient of 5 vertical feet in height, to allow the engine to get up momentum, are advisable.[2] But where it is possible to get round an obstacle by curves these should be preferred to gradients. In the very roughest country a reduction of curve-radius from 600 to 300 feet greatly reduces the cost, while in ordinary rough country 10° and 12° curves (578- and 478-feet radius) furnish the most expedient minimum curves. Local traffic and towns should be served by increasing the length of the line. Trestling should be used everywhere instead of heavy masonry or earthwork of above 10 to 15 feet in height. Split stringers, sills and caps, without mortices, where every piece can be taken out and renewed without much trouble, should be used. Terminal and station facilities should be of the cheapest kind. Level-crossings are everywhere used, even in the largest cities, in the United States. Fencing is often dispensed with, except in cattle-grazing districts.

All these matters are differences of degree and detail rather than of kind or of principle between light lines and heavy for a railway; and the general problem the American engineer sets before himself is—not which is the best possible constructed line for serving any probable traffic permanently between two places—but, of all possible lines passing through a given country, which is the one that, in a series of years after construction (taken sufficiently long to include the period of renewal of temporary works), will give at the same time a minimum of interest of first cost, and a minimum of cost of operation of the traffic likely to be developed during that period? And as the American ideal railway transcends everything yet reached in any country, and the best work yet accomplished is looked upon as a temporary or transition stage of progress, all solutions of the problems are given in a more or less tentative form as regards the data employed and

[1] Mr. A. M. Wellington: Transactions of the American Society of Civil Engineers, vol. xiii. 1884, p. 197.

[2] "Railroad Gazette," March 27, 1885.

figured conclusions, while the principles remain true throughout all varying applications.

It is impossible to do more than give a slight sketch of these principles, and a very few of the data, in this Paper, and the Author would refer amongst others to the following writers who have treated these subjects at length. Mr. Hermann Haupt, Professor G. L. Vose, Mr. William H. Searles, and Mr. A. M. Wellington.[1] Mr. Searles gives his results mostly in a mathematical form, which permit a clear view to be taken of the more salient points. Mr. Wellington's valuable book is now out of print, but he is engaged in preparing a new edition with later data and results. A very short and imperfect notice of the results will now be given.

Mr. Wellington begins by analyzing the cost of working thirteen of the principal railways, and of all the lines of the three States of Ohio, Massachusetts, and New York. Since he wrote, the Census Report of 1880 on Transportation has been published, which gives the operating expenses of all the railways in the United States for the previous year. Treating the abstract of this in the same manner, the following results are obtained. (See next page.)

The actual cost of operation in the census year 1880 was, for freight-trains \$0·98 per train-mile; for passenger-trains, \$0·76 per train-mile. Mr. Wellington assumes the average cost of all trains to be \$1 per train-mile, a convenient unit generally adopted. Comparing the results in the last column with those obtained by him in 1877:—

——	Engines.	Cars.	Train Wages.	Train Expenses.	Maintenance of Way.	Total.
Average of thirteen railways . . .	30·7	14·4	17·6	62·7	37·3	100
Average of railways of three States .	28·8	14·5	17·9	61·2	38·8	100
Average of all railways in the United States. . . .	25·3	13·8	28·4	67·5	32·5	100

Applying these data to the consideration of a division 100 miles long, it is shown that for small variations of length the total

[1] Haupt: "Van Nostrand's Magazine," vol. ii. p. 593; G. L. Vose: "Manual for Railroad Engineers and Engineering Students," 1881; Searles: "Field Engineering," 1885, chap. iii.; "Theory of Maximum Economy of Grades and Curves," 1883; Wellington: "The Economic Theory of the Location of Railways," 1877.

TABLE.

Operating Expenses U.S. Railways, 1880.				Per cent.
Description.	Amount.	Per cent.	Per cent.	
	Dollars.			
Fuel for locomotives	32,836,470·47	9·31	..	25·31
Water-supply	2,388,866·66	0·68	..	
Oil waste, &c.	3,754,671·25	1·06	..	
Repairs of locomotives . . .	21,830,963·43	6·19	..	
Locomotives, total . . .	60,810,971·81	..	17·24	
Repairs, passenger cars . . .	10,558,823·99	2·99	..	13·79
„ freight „ . . .	22,595,553·09	6·40	..	67·5
Cars	33,154,377·08	..	9·39	
Wages, &c., locomotive service .	27,239,567·54	7·72	..	28·40
„ passenger . . .	12,002,415·65	3·41	..	
„ freight	28,935,135·96	8·21	..	
Wages, supplies, &c. . . .	68,177,119·15	..	19·34	
Train expenses, grand total .	162,142,468·04	..	45·97	
Repairs, road-bed and track . .	39,603,076·09	11·23	..	32·50
„ renewal of rails . . .	17,243,950·43	4·89	..	
„ „ ties (sleepers)	10,741,577·06	3·04	..	
„ bridges	9,009,097·20	2·55	..	
„ fences, crossings, &c. .	1,480,925·69	0·42	..	
Maintenance of way . . .	78,078,626·47	..	22·13	
Train expenses and maintenance of way	240,221,094·51	..	68·10	100
Repairs and buildings . . .	7,644,121·24	2·17	..	
Telegraph expenses	3,576,476·45	1·01	..	
Agents and station service . .	36,767,299·20	10·42	..	
Station supplies	2,871,932·69	0·81	..	
Station, &c., service . . .	50,859,829,58	..	14·41	
Salaries of officers and clerks .	12,215,850·06	3·46	..	
Legal expenses	2,457,904·98	0·70	..	
Taxes	13,283,819·10	3·77	..	
Insurance	926,633·77	0·26	..	
Stationery and printing . . .	2,692,011·00	0·76	..	
Outside agencies and advertising	4,737,310·56	1·34	..	
Contingencies, &c.	21,328,325·70	6·04	..	
Loss and damage	3,456,264·49	0·98	..	
Expenses not above specified .	621,077·00	0·18	..	
Establishment, &c. . . .	61,719,196·66	..	17·49	
General control expenses .	112,579,026·24	..	31·90	
Total expenses	352,800,120·75	..	100·00	

cost of operation is very little altered, especially if no alteration is made in the number of stations or stoppages. For each additional mile the extra expense of operation does not exceed 42 per cent. of the average cost per mile. For longer distances a larger percentage must be allowed; but, for those in practice, 50 per cent. is found to be sufficient. In projecting a new line the capitalized value of reducing the length 1 mile would be, at 5 per cent. interest, for each daily drain (round trip), £1,100. Against this, however, is the set-off that sometimes local traffic is better served by a longer line, and the expense is recouped by mileage rates. If 1 mile of line could be cut out of the Pennsylvania Railroad, where it has fifty-one trains each way daily, the saving in operation would justify an outlay at the above rate of £56,100.

The testimony as to the extra cost entailed in operating trains on curves varies very widely; but it is claimed that besides allowing much sharper curves to be worked, the use of the bogie-truck reduces the expense to one-half of that found to exist with the long rigid wheel-base of European lines. Mr. Wellington is of opinion that the extra cost due to the curves is comprised within two items, the wear and tear of track, and the additional fuel used in hauling round the curves. He estimates from the data at hand that the extra wear of rails is less than 10 per cent. per degree of curvature, and track-maintenance and ties average 4 to 5 per cent. increased expenses for the same; or for 1 mile in length of continuous curve of 11° 20′ (512-feet radius) 100 per cent. extra wear and tear on the former, 50 per cent. for the latter.

The extra cost for haulage is estimated to lie between 1 lb. per ton per degree of curvature for slow speed, and ½ lb. for higher, but no satisfactory conclusion has been reached on these points.[1]

[1] Mr. Wm. F. Shunk gives experiments on the Tyrone and Clearfield Railway, where with a rolling friction of 7 lbs. per ton to a train 350 feet long, a curve of 10° entailed a farther friction of 4·6 lbs. per ton; and a 12° curve with a train 720 feet long gave a resistance of 9·4 lbs. per ton. It was his opinion that the length of a train modified the resistance. Mr. O. Chanute considers that the resistance is inversely as the radius; and gives the formula—

$$\text{Resistance due to curvature in lbs. per 2,000 lbs.} = 0 \cdot 6 \times \frac{5{,}730}{\text{radius in feet}}.$$

This differs from the results of Von Röekl's experiments (over 2,000 in number) in Europe, who gives

$$\text{Coefficient of resistance due to curvature} = \frac{0 \cdot 6504}{\text{radius in metres} - 55} = \frac{0 \cdot 20}{\text{radius in feet} - 17} \text{ nearly.}$$

Mr. Searles takes the resistance to average ½ lb. per degree of curvature.

Mr. Wellington estimates the fuel consumption to be increased by 60 per cent. on a length of curvature offering the same resistance as a mile of level straight track, which is found to be 600°. The cost per train-mile per degree of curvature is thus 0·0875 when the train-mile costs 100; or per year per daily train it comes to 24·375; and, equating the value of curvature and distance, it is found that the operating cost of 1° of curvature is equal to that of 4·7 feet of distance, or 1 mile of distance equals 1120° of curvature. In estimating therefore the comparative values of two different lines between the same points, the sums of the interest on first cost in each case, and of the operating cost of the probable number of trains so far as affected by distance and curvature, can be stated and balanced.

The expense of gradients is a more complicated question, as it involves not only considerations respecting the maximum or ruling-gradient, but the direct cost of overcoming the total rise and fall in the line. The two problems presented are not only separate but different in their nature. The first limits the weight of train that the engines can draw on the line, the second is an important factor in the operating expenses. Every foot of rise implies a foot of fall, excepting the difference between the termini of a line; and the sum of the ascents and descents may be called the summit-elevation. It is obvious that when a train goes a round trip, each foot of summit-rise implies 2 feet of ascent and 2 feet of descent, thus entailing twice the cost of terminal elevation. Any two lines may therefore be compared directly by taking the total rise and fall in each and dividing by two. Using the ordinary formula for train-resistance[1] it is found that, at a speed of 15 miles per hour, 22-feet rise per mile, and at a speed of 30 miles per hour, 31 feet per mile, doubles the resistance. Taking an average speed of 20 miles per hour, a gradient of about 25 feet per mile may be

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Mr. Wilder, on the Erie Railroad, found by experiments with his dynamometer on trains in regular work on the whole length of that road, that with a friction on level straight lines of 3¼ lbs. per ton the curves added $\frac{1}{10}$th lb. per ton per degree of curvature to the resistance.—Mr. Reuben Wells, of the Louisville and Nashville Railroad, estimates that the power consumed in drawing a train over 100 miles of road, with modulus of curvature equal to 10°, would haul the same train over 110 miles of tangent. The modulus of curvature is equal to the average angle turned through in running 1,000 feet.

[1] Mr. D. K. Clark gives resistance $= \dfrac{v^2}{171} + 8$. Mr. Searles gives resistance $= 5{\cdot}4 + \left(0{\cdot}06 + \dfrac{0{\cdot}0006 \text{ weight of engine}}{\text{total weight of train}}\right)v^2$.

taken as doubling the resistance, and used for estimating the operating cost. The following ratios of extra expense over that on a level line are then found for each 25 feet of rise and fall. Repairs of engines and cars, none, though 10 per cent. may be allowed; repairs to rails and track, 10 per cent.; the two items together increasing the rate of train-mileage 4 per cent.; fuel, 60 per cent. increase, the fuel saved in descending not compensating for the extra cost in ascent. The total extra cost per train-mile is 8 per cent. when the train-mile cost is 100; and the yearly cost per daily train, round trip both ways, becomes 208 for each foot of summit elevation ($2·08 when the train-mile is valued at $1). The capitalized value of saving 1 foot of rise and fall on gradients over 40 feet per mile, and not exceeding the ruling gradient, is $41·60 at 5 per cent. interest; and 1 mile of distance is equal to 131 feet of rise and fall in operating expenses; or 1 foot rise and fall to 40 feet of distance, or to 8°·5 of curvature.

Ruling-gradients limit the weight of trains which the locomotive can haul, and it is usual to consider each division of a line separately, and adapt it as far as possible to the same method of working throughout. The length of engine-stage varies in the United States from 50 to 200 miles or more, and may average about 75 miles; and it is found most economical to concentrate any exceptional features of a line, such as extremely sharp curvature or very steep gradients, in as few engine-stages as possible, and to operate these with special or heavy engines with many drivers, or with assistant engines. Each division of the line will therefore have its own ruling-gradient adapted to the conditions of the country and to the nature of the traffic, which is sometimes much heavier in one direction than in the other. In this case the ruling-gradients are so adjusted that the same engine-effort is required to haul the light train with empty cars the one way as the heavy train the other way.

The traction-force of engines is found to vary from one-third to one-seventh of the weight of the drivers in ordinary conditions, and may be taken as averaging one-fifth. Eight-wheel drivers usually have 60 to 80 per cent. of the weight upon the drivers, while Decapods take as much as 90 per cent. The Fairlie engine, with its whole weight on the drivers, is never used in the United States. The resistance from gravity alone is, for every foot of gradient per mile, 0·0001894 per cent. of the weight. To fix the ideas, the rolling friction may be taken as 10 lbs. per ton. Thus the total resistance per ton will be = gradient in feet per mile

$\times$ 0·0001894 + 10, and the ratios of load to traction-power will be as follows per each 2,000 lbs. (short ton):—

Gradient in feet per mile . .	Level.	Feet. 10	20	30	40	50	60	70	80	90	100	150	200	300	400	500
Resistance in lbs. per ton . . .	10	14	17·6	21·4	25·1	28·9	32·7	36·5	30·3	44·1	47·9	66·9	85·8	123·7	162	199
Ratio of gross load to traction . .	200	145	114	94	79	69	61	55	50	45	42	30	23	16	12	10
Per cent. increase of engine tonnage per foot change of grade	4	3·1	2·4	2·0	1·7	1·5	1·4	1·4	1·2	1·1	1·1	0·9	0·8	0·8	0·8	0·8

It is found that when the ruling-gradient changes slightly, the corresponding percentage of change in the engine-tonnage is nearly uniform per foot. But the amount of this percentage of increase or decrease in the engine-tonnage required varies considerably with each gradient, being nearly five times as much on a level as in a 150-feet gradient. The change in engine-power may be made in two ways: in the number, or in the weight of the engines used. In the first case the cost of fuel, wages, oil, &c., comes to 50 per cent. more than that of operating a single engine, while it is estimated that an engine of double weight increases the expenses by 42 per cent., though this is very uncertain. But an average may be taken of 48 per cent. increase per train-mile, consequent on a change of ruling-gradient, requiring a double engine-tonnage to operate. Or, allowing three hundred and twenty-five round trips to be made per year, the cost per daily train per mile of road would be 48 $\times$ 325 $\times$ 2 = $312·00 when the train-mile costs $1. The operating cost of this for an engine-stage, say 100 miles in length, will be found by multiplying this sum by the rate per cent. of change of engine-tonnage given in the last Table for each grade, and the capitalized value, say at 5 per cent. interest, by multiplying these sums by 20, which gives for each change of 1 foot per mile from level a value of $24,960, and from 40 feet per mile of $10,608. These values apply, however, only to trains running with the maximum loads permitted by the gradients.

The question of the use of assistant engines is of the highest practical importance, but while general rules and recommendations have been arrived at by experience, each length of line presents problems which can only be solved subject to the special conditions met with. It is, however, recommended to concentrate

the maximum resistances from curves and gradients in as short lengths of the line as possible, and to work these portions with assistant engines, so arranged in number and weight as to be capable of hauling through their stage the maximum train hauled in the level. It is found that from 60 to 80 miles a day is fair work for an assistant engine, with frequent short runs, while it can do 100 miles in favourable circumstances. The work should be so adjusted as to keep them in constant employment, and their use conduces to great economy in first cost, as well as to economy of operation. The following Table is given by Mr. Wellington to show the adjustment of gradients for assistant engines, according to the average daily performance on all American railways:—

Ruling Grade worked by One Engine in Feet per Mile.	Grade at which the same Train can be drawn by the aid of					
	One Assistant Engine			Two Assistant Engines		
	Of equal weight on Drivers.	Heavier by		Of equal weight on Drivers.	Heavier by	
		20 per cent.	40 per cent.		20 per cent.	40 per cent.
Level	24	29	33	46	54	62
10	42	48	53	70	80	90
20	59	66	72	92	104	116
30	76	84	91	113	126	138
40	92	101	109	133	147	160
50	107	117	126	152	167	180
60	122	133	142	169	185	199
70	136	148	158	185	201	216
80	150	162	173	201	217	232
90	164	176	187	216	232	247
100	177	189	201	230	247	261
110	190	202	214	..	..	..
120	203	215	227	..	..	..
130	215	227	239	..	..	..
140	227	239	251	..	..	..
150	238	250	262	..	..	..

The above Table is calculated on the assumption that the rolling-friction on the level is 10 lbs. per ton; for lower frictions the gradients are proportionately lessened. Also it is understood that all gradients must be properly compensated for curvature. The use of the assistant engines as headers or pushers can only be determined by the conditions of the traffic; but those who believe that the length of a train on a curve determines the amount of extra friction prefer pushers in order to lessen this. Assuming the cost of operating an assistant engine to be 47 cents per train-mile, the additional cost per year for daily trains will be $47 \times 2 \times 325 =$

\$305·50, when the ordinary train-mileage is \$1. The capitalized value of this, at 5 per cent. interest, is \$7,110.

Lastly, as the heavy traffic on through-lines is often much greater one way than in the other, special attention is given to balancing the resistances on the whole line, so as to ensure that the full engine-power required to take the loaded trains one way shall be required to take back the empty cars and partially-loaded trains the other way. This is done by adjusting the ruling-gradients and curves on the principles already mentioned; but with special reference to the weight of trains and the power of the engines employed; although it is perhaps the most important consideration affecting the whole alignment, it is, when all the other conditions are duly arranged, the easiest to accomplish. The whole of the preliminary problems taken together contain the solution of this final problem, and should be so considered throughout.

In conclusion, the Author cannot refrain from expressing the diffidence he feels in dealing with this important subject, especially in its present transition stage, and he has only ventured to do so in the hope that the statements made may be accepted as opening out inquiries regarding matters of great interest, in which further information and enlightenment is desired.

The Paper is accompanied by numerous illustrations, from which Plates 2, 3, and 4, and the Figs. in the text have been engraved.

(*Paper No. 2098.*)

"The Principles to be Observed in the Laying-out, Construction and Equipment of Railways in Newly-Developed Countries."[1]

By James Robert Mosse, M. Inst. C.E.

Railways in undeveloped countries present the following contrasts to railways in those that are settled. In England, and more or less in Europe, they have been constructed solely as private commercial enterprises, whereas in new countries they are more commonly undertaken by the State, either wholly or in part. Each system has naturally its advantages and its evils. State interference, which might be very prejudicial in England, is essential in new and poor colonies, where public works, which at first could not pay commercially, are nevertheless indispensable to the development and prosperity of the country. In other words, if public works be undertaken, they must be in some manner assisted by the Government; and if so, they will, in the Author's opinion, be constructed more substantially, and be worked more advantageously to the community, when owned by the State than when in the hands of a private company. In the first case, the advancement and prosperity of the country is the chief object in view; in the second, it is the commercial profit of the shareholders.

In England railways have been undertaken one after the other, where the population and business required better means of communication; as, for instance, from Liverpool to Manchester, afterwards to Birmingham, and then to London; whereas in North America and in Australia, railways have been projected on a far larger scale, not so much to give facilities for existing business as to favour the growth of population and commerce. Take, for example, the chief southern and western railways in the United States. The line from Mobile through Cairo to Chicago, some 845 miles long, and the three lines to the Pacific; and then take, in Canada, the Intercolonial Railway from Halifax to Quebec, 687 miles, the Grand Trunk, from Quebec to Sarnia, say 673 miles, and especially the Canadian Pacific, from Montreal to Port Moody, a

[1] The discussion upon this Paper was taken together with that upon the preceding and following ones.

distance of some 2,900 miles. This latter railway, constructed solely to open up the far west of Canada, is particularly worthy of record; the company formed to make and work it has been assisted by a donation of £5,000,000 sterling, and by a grant of twenty-five million acres of land from the Dominion of Canada. The railway lands extend in breadth 24 miles on each side of the line, the Government and the Company owning alternate lots; and free grants of 160 acres are given to any one who will settle on and cultivate them. There can be no doubt of the wisdom of this policy, and that Canada will soon reap a rich reward for her expenditure on this work. Similar principles prevail in Australia, in other colonies, and in India. The locomotive is not so much the transporter of commerce as the pioneer and the developer of civilization.

The different circumstances existing in an undeveloped and in an old settled country naturally cause a contrast in the class of works; the requirements of the former are less than those of the latter; the one is poor, the other rich; and the works must, as far as practicable, correspond with the circumstances in each case. It should, however, be remembered that the large geographical features of many countries, as compared with England, for instance the mountain ranges and the large rivers of Canada and India, often necessitate heavier works than usually prevail in this country.

Class of Railway.

In a level country, with small population and little traffic, due allowance being made for its subsequent increase, a light railway will suffice. But in a hilly country where steep gradients are imperative, or with a large anticipated traffic, heavy engines become indispensable, and they in turn require a strong permanent way and heavy bridges. In fact, the class of railway to be made must from the first regulate the design of every portion of it; everything should be rigidly in keeping, and though economy must be studied, and the capital available for the railway forms an important factor in the design, the general suitability of the work for its requirements is equally important.

Laying-out.

As regards the principles of laying-out a railway, the line should be suited to the country; the practical question being the shortest and most level route available between any given points. With

Ordnance maps, or with a fairly open country, this exploration and survey are comparatively easy; but where dense forests prevail, the case is far more difficult. The Author knows of no better method of conducting a railway survey through woods than that practised in America. The party generally consists of four surveyors with from twelve to twenty men as chain-men, axe-men, carriers of baggage, &c.; they are furnished with tents and provisions, and where practicable with two or more horse-teams. The surveyors include the chief of the party, the theodolite man, the leveller, one man taking cross-sections, and one spare surveyor.

After obtaining what knowledge of the country is practicable from its general features and from the course of rivers, the chief reconnoitres with an aneroid and a compass some 2 or 3 miles in advance of the party, and he then directs the courses to be taken with the trial lines. The theodolite man then cuts these courses in straight lines (not trusting to the compass) puts in pegs every 100 feet, enters in his note-book the courses, width of rivers and streams, and sketches the general topography of the country. The third surveyor records the levels, and the fourth man follows the level, taking at every 100 feet length cross-sections with a clinometer graduated to percentages of inclination, so that if the index mark 6, and the distance be 400 feet, the difference of level between the two points would be 24 feet; and a figured sketch of each cross-section is then entered in the note-book. By this system, the line cut through the forest is levelled and cross-sectioned on the same day; in fact, the ground covered by the cross-sections is thoroughly ascertained. Where the forest is not too thick, an average of 1¼ mile of line can be thus surveyed in one day, provided the axe-men and chain-men are experienced. In the United States all field-work done during the day is plotted the same evening, so as to guide the next day's operations, a practice which, though very laborious, effects great saving in time. After thus finding by trial lines a good route, the railway, as termed in America, is "located," that is pegged out at distances of 100 feet, and when necessary this "location" is similarly improved until a satisfactory route has been found. As a rule, American engineers are very skilful and particular in making these "locations." They always use a chain of 100 feet, and their tapes are divided into feet and tenths.

Gradients.

Cases occasionally occur where a summit-level, with a given maximum rate of inclination, regulates the route irrespective of

the suitableness or otherwise of the intermediate ground. A case of this nature exists on the Midland line of the Mauritius Railway, which has a rise of 1,817 feet in 16 miles, with some intermediate gradients of 1 in 27; and another instance is to be found in the Nanu Oya extension of the Ceylon Railway, where, "with the exception of pieces aggregating 1¼ mile in length, the gradient of 1 in 44 prevails for 18½ consecutive miles," and on another portion of this line the same gradient is continued for 9½ miles; the total rise of the extension amounts in about 40 miles to 3,380 feet, the Nanu Oya station being 5,293 feet above the sea. In these cases, ground had evidently to be found to suit the maximum gradient permissible, instead of the gradient being made to suit the ground, and thus give the least amount of earthwork.

The maximum gradient, which should in general be adopted on a railway to be worked by ordinary locomotives, depends upon the character of the country, the capital available for the construction of the line, the amount of traffic anticipated, and on the speed required.

From the Author's experience in working for five years the steep gradients on the Mauritius Railway, he came to the conclusion, that, as far as practicable, a gradient for locomotive-traction should not exceed 1 in 40; although he has since seen such rough country in Ceylon, that economy would compel him to adopt a gradient of 1 in 30, to be worked if necessary by two locomotives.

Where a rising gradient is required for several miles, for instance of 1 in 60, it is safer to adopt a steeper gradient, say, 1 in 55, with lengths where practicable comparatively level, rather than that the whole line (stations excepted) should be of one uniform inclination. In the former case, a runaway train would be brought under control on the level, which it might not be in the latter; and the knowledge that at a particular spot a runaway train will stop, gives to the drivers and guards greater coolness under such circumstances.

Curves.

However desirable it may be to adopt easy curves, economy on all mountain railways necessitates sharp curves; and the question is then to decide upon the minimum curve which is safe and workable without excessive wear. In America, with a gauge of 4 feet 8½ inches, curves of from 330 feet to 400 feet radius are traversed by carriages carried on four- or six-wheeled bogie-frames, hauled by four-wheeled coupled engines having a wheel-base of 6 or 6½

feet, and supported upon a bogie-frame in front. American locomotives are made with greater play, they therefore go more easily round curves, and they adapt themselves better to the great inequalities of the permanent way caused by the climate, than would be the case with English locomotives. During a Canadian winter the only way of keeping the rails level is by "shimming up" or packing them with pieces of wood from ½ inch to 3 inches in thickness, and these packings must be constantly changed, for the rails will vary in level 6 inches in a night, and in cases of extreme frost after rain, they will sometimes rise 12 inches in as many hours. It is consequently a common practice to tap the ice in the side-drains with a crow-bar, so that by letting out the water the rails may come more to a level. A curve of 1° at the centre on a chord of 100 feet, which is equal to a radius of 5,730 feet, is ordinarily said in America to produce friction or resistance equal to a rise of 1¼ foot per mile on a straight line, that is, a gradient of 1 in 4,224, the gauge being 4 feet 8½ inches.

On the Intercolonial Railway, with a gauge of 4 feet 8½ inches, Mr. Sandford Fleming, C.M.G., M. Inst. C.E., decided that the maximum gradient, which on the straight, or on a curve of not less than 5,730 feet radius, was fixed at 1 in 100, should on a curve of 2,865 feet radius be reduced to a grade of 1 in 111, and on a curve of 1,910 feet radius to an inclination of 1 in 125, the latter being equal to a reduction of 10·60 feet per mile as compared with the gradient of 1 in 100 on a straight line. This agrees fairly with Professor Rankine's rule. On the Nanu Oya extension of the Ceylon Railway (gauge 5 feet 6 inches), opened for traffic on the 20th of May, 1885, a large portion of the curves varying from 6 to 9 chains radius are on the gradient of 1 in 44, which prevails for many consecutive miles, and on the few exceptional curves of 5 chains radius the gradient has been reduced to 1 in 50¾, equal to a reduction of 16 feet per mile.

Gauge.

This question has been often discussed, and the Author will only record his opinion that in general the gauge should not be less than 4 feet, nor wider than the Irish gauge of 5 feet 3 inches, the mean of these widths being practically the standard gauge of 4 feet 8½ inches. It has already been shown that the width of the gauge *per se*, other items being unaffected by it, can make but little difference in the total cost of a railway.

CONSTRUCTION.

Whatever be the class of railway adopted, a fair margin of safety against contingencies should always be provided. Both for economy in first cost, and for convenience in working, the design of the works should be ample and the execution substantial; nothing can be more unsatisfactory than additions required on account of an insufficient design, nor more costly than alterations necessitated by bad materials or workmanship.

EARTHWORK.

The dimensions and the slopes of cuttings and embankments depend chiefly upon climate, rainfall, and the nature of the ground. For instance, on the Intercolonial Railway of Canada, in wet soil the earth cuttings for a single line of rails are 32 feet wide at the base, with ditches on each side 4 feet deep below formation level, whereas in a milder climate a width of 20 feet would suffice; slopes of cuttings can also be made much steeper in temperate climates than in those where frost often causes them to slip to a slope of 4 to 1.

Where land is cheap, but plant expensive and scarcely available, earthwork is done more speedily by carrying the excavation to spoil, and by making up the embankment from side-cutting, than by the use of wagons. This practice, and the ploughing and scraping on the Canadian Pacific and on the West Shore Railways, are very common in America; and the wagons there used are generally "side-tipping cars," as more suitable for forming the narrow embankments required for a single line of way.

On some railways in the United States it was formerly customary to pay per cubic yard both for excavation and embankment, leaving it optional with the contractor either to transport the material, or to form the embankment from side-cutting, a practice still followed with coolies and basket-work in India.

On the Southside Railway in Virginia, the side slopes were pegged out with a level at distances of 100 feet, depending on the rise or fall of the ground above or below the centre line, so that the average depth of cutting (or height of embankment) on each cross-section might be accurately determined. The cubic content of earthwork, according to the width of formation and the ratio of the slopes, was then obtained from tables calculated for each tenth of a foot in depth. To the cubic content corresponding to the average depths thus found, an addition was made from an "error

table" to give the true prismoidal content. Thus, take a cutting of 20-feet base with slopes 1 to 1, say, 2 feet deep at one end, and 30 feet deep at the other, length 66 feet.

	Cubic yards.
Then content for mean depth of 16 feet =	1,408
Add for error 30 feet − 2 feet = 28 feet =	160
True cubic content	1,568

The error E in cubic yards always additive $= \dfrac{L \times D^2 \times R}{27 \times 3}$;

where L = length of excavation in feet;
D = half difference of the depths of cutting at each end of the excavation in feet;
R = ratio of the slopes.

In the above case, instead of in feet—

$$\frac{66 \times 14^2 \times 1}{27 \times 3} = 160 \text{ cubic yards.}$$

These tables are more detailed than those of the late Mr. G. P. Bidder, Past-President Inst. C.E., being calculated for each tenth of a foot in depth.

Waterway.

The provision necessary for floods forms one of the most important items in the construction of railways, and to obtain information as to flood-levels in an unsettled district is often extremely difficult. The requisite waterway depends chiefly upon the general features of the country, and the rainfall, especially upon the maximum fall per day during the wet season.

In England, falls of 3 inches in depth per day are most unusual; but in many parts of the tropics, having a rainfall ranging from 100 to 200 inches per annum, falls of 10, 12, and even 18 inches in twenty-four hours have to be provided for.

To avoid the trouble and expense which sometimes arise in repairing "washaways," and providing additional bridges, after a railway has been opened for traffic, ample waterway, having a safe margin for all contingencies, should always in the first instance be provided. The Author allowed a margin of 5 feet in height to the underside of the girders, above the highest known flood-level; and as regards width, he considered it better to err on the safe side.

Bridges.

The choice of a suitable site, for crossing large rivers within certain limits, often forms the chief point in the selection of a railway route. The principal desideratum is a solid foundation with a shallow depth of water. Where elaborate appliances are costly, and where skilled labour is both uncertain and expensive, simple measures suited to the customs of the country will generally be found preferable. Thus, in India, the well-system is understood and easily worked by natives; and in North America, with timber abundant and cheap, piling and timber flooring are more frequently adopted than cofferdams and concrete.

Where stone is distant from the works, and haulage expensive, small rivers and streams are often crossed in the first instance by timber-work, the stone being brought to the spot after the line has been opened for traffic, when either an arch can be turned, or iron-work substituted for timber. Whether timber structures should in any case be erected, their life being only some ten years, must depend upon the class of railway to be made, upon the capital available, and upon the individual local circumstances; but if put up as a temporary measure, the Author knows of no plan of timber bridge, for spans up to 150 feet, so simple, cheap and efficient as the common Howe truss. The difficulty and cost of transport are generally so great, that for all bridges the chief desideratum is the lightness of each piece, especially when it has to be carried by hand; and as regards iron-work, the difficulty of getting good riveting done by natives induces the Author to prefer the "pin-connected" system as in the Warren girder, and those generally adopted in the United States, even although the bridge be not so stiff as when riveted.

Culverts and Stream-Diversions.

Where the Intercolonial Railway of Canada passed over short but deep ravines, it was common, in 1870, to divert the stream from the upper toe of the embankment, and to pass it on that level under the embankment through a tunnel, frequently formed in rock, rather than to build a culvert at the lowest part of the ravine; and the tunnel was not only cheaper, but more expeditious in making, than the culvert, for the former could at any time be excavated by common labour, whereas the latter could only be built by masons in the summer.

This practice has been extensively followed on the recent Ceylon railway extensions, passing chiefly through sidelong ground as steep as 3 or 4 to 1. The streams were frequently diverted, as high as practicable, through the solid ground, sometimes to near the mouth of the adjacent cutting, where they were crossed by 6-feet rolled girders resting on abutments, say 20 feet long; whereas an arched culvert, some 150 feet in length, would have been necessary at the bottom of the ravine. Great care was taken in making the stream-diversions of ample cross section, both as to width and slopes, as well as in protecting the toe or steps of the culvert on the lower side from being undermined or injured by heavy floods; and when streams were thus diverted, the ravine on the upper side of the embankment was, in order to prevent water from lodging, filled up to formation-level with surplus excavation, either from the adjacent cutting or stream-diversion. This system has proved very satisfactory.

Masonry.

The choice lies between light ashlar masonry and flat-bedded rubble, well bonded, forming in the aggregate a larger mass. The Author has seen, in the United States, piers supporting timber bridges, built of superior ashlar, fully 80 feet in height, and only 4 feet thick at the top, with a batter ½ inch to the foot on each side; but in general thicker masonry of a rougher class, built in Portland cement mortar, is preferable. In the tropics it is most difficult to get the stones well wetted and cooled before being bedded. They are mostly of a temperature that gives the mortar no chance of properly setting. For this reason concrete should be mixed with more water in the tropics than in temperate climates; and though abutments and arches of cement concrete are successfully used in temperate latitudes, they are subject to much greater risk, and are therefore not so suitable for hot or for cold climates.

Permanent Way.

The rails (of steel) may vary from 40 to 75 lbs. per yard, with fish-plates, fastenings, dimensions of sleepers, depth of ballast, &c., all corresponding to the rail used. A rail weighing less than 60 lbs. to the yard is, however, seldom advisable. For newly developed countries the flat-bottomed rail, in lengths of 21 feet, is the easiest to lay, having fewer parts to transport and fix. There should be at least seven sleepers to each rail, which should be fixed at the joints, and at least to one intermediate sleeper, in

the middle by fang-bolts, the other sleepers having strong dog-spikes; guard-rails should also be used on all curves of 10 chains radius and under. The Author considers that in cold climates, on account of the frost, and in the tropics, because of the heavy rains, only small broken stone, 10 inches in depth, should be used for bottom ballast, the top layer, 8 inches deep, being of good gravel; and that the boxing should cover the sleepers, so as to protect them from the sun. A strong permanent way, with first-rate ballast, ensures great economy in future maintenance. Green native sleepers, both in Canada and in India, are in general very perishable, and in the tropics it is preferable to import creosoted Baltic fir sleepers.

Stations.

However amply stations may have been originally designed, increasing traffic has required them to be so continually enlarged that it would be difficult to find any station at this date with the accommodation provided forty years ago. A station too large for future requirements has been rarely, if ever, seen; hence ample provision, especially in land, should be made in the first instance. For a single line in newly-developed countries, the Author recommends a siding and platform being placed on each side of the main line at every station, so that three trains may pass there at the same time. Each passenger-platform should in general not be less than 300 feet in length, for the trains being few are often long. The length of the sidings will depend upon the anticipated traffic; but in Canada, passing-sidings to hold two trains were, as a rule, made not less than 2,000 feet long. The goods-shed and sidings should be placed on one side, so as not to interfere with the passenger-trains. Having personally experienced great inconvenience in conducting traffic with insufficient station accommodation, the Author would emphasize the necessity and economy of providing an ample design in the first instance. The buildings should be simple, and placed so as to be capable of enlargement, and there should be plenty of space in the station-yard for additional sidings, as otherwise the enlargement of stations becomes most difficult and expensive. Though the design should be extensive, only such portions as are necessary need from time to time be carried out.

Equipment.

Perhaps more than any other item, the equipment depends upon the nature of the railway and the traffic; for the steeper the gradients, and the heavier the traffic, the greater must be either

the number of the locomotives or their weight. It is true economy not to overwork rolling-stock—especially engines; of which to meet repairs, and ordinary contingencies, there should be a margin of, say, 25 per cent. With the exception of Canada and Australia, where locomotives are manufactured, the engines and ironwork for rolling-stock are mostly imported into the Colonies from England, the woodwork being very well made there from the most suitable native timber—from pitch-pine in America, and from teak in India and elsewhere in the East.

The rolling-stock provided for the Nanu Oya extension of the Ceylon Railway, having a gradient of 1 in 44, with curves from 5 to 8 chains radius, the gauge being 5 feet 6 inches, is as follows:

Locomotives from Messrs. Kitson and Co., cylinders 17 inches in diameter; length of stroke, 26 inches; driving-wheels, six coupled, 4 feet 5 inches in diameter; wheel-base, 9 feet 6 inches; but as the leading pair of driving-wheels are flangeless, the fixed wheel-base may be said to be only 4 feet 5 inches. The bogie has four wheels of 3 feet diameter, with lateral play in the centre, the wheel-base being 6 feet. The firegrate area is 23½ square feet; the total heating surface, 1,247 square feet.

	Tons.	Cwt.
Weight on leading wheels coupled	11	7
" driving " "	12	12
" trailing " "	11	7
" bogie "	10	0
Total weight in running order	45	6

The side-tanks of the engine contain 600 gallons. The tender, 1,800 gallons. Total, 2,400 gallons.

The engines are provided both with a steam- and with a hand-brake. Ten were ordered for working the extension of about 40 miles. The Resident Engineer, Mr. Edward Strong, M. Inst. C.E., reports as follows: "These engines work remarkably well, with practically no flange wear—they are a perfect success for working on 5-chain curves."

Carriage and Wagon Stock.

The carriage and wagon underframes are of iron: the former 40 feet long by 8 feet 4 inches wide, the latter 31 feet long by 7 feet 9 inches wide.

Both these carriages and wagons are supported on a four-wheeled bogie at each end, the wheels being 3 feet 6 inches in

diameter, and the rigid wheel-base 6 feet. They are all fitted with Clark's chain-brake, which can be worked either from the tender or from the brake-van. The ordinary four-wheeled goods wagons, having a rigid wheel-base of 7 feet 6 inches, run round 6-chain curves so easily, even on a gauge of 5 feet 6 inches, that the purchase of many additional wagons supported on bogie-frames is not considered probable.

The locomotives working on gradients varying from 1 in 27 to 1 in 40 over a rise of 1,817 feet on the Mauritius Government Railways, are six-wheeled coupled side-tank engines, 3 feet 6 inches in diameter, with cylinders 16 inches in diameter, having a length of stroke of 22 inches, and a rigid wheel-base of 15 feet. Their weight with fuel and water is 37 tons each.

There are also some eight-wheeled coupled saddle-tank engines with wheels 4 feet in diameter and rigid wheel-base of 15 feet 6 inches; but the joints of the coupling-rods connecting the leading- and trailing-wheels with the driving-wheels, are fitted with a ball and socket, so as to allow the requisite play in going round curves. The cylinders of these engines are 18 inches in diameter, length of stroke 24 inches, they weigh in running order 48 tons, and worked very satisfactorily.

The rolling-stock, to be adopted on any particular railway, must depend entirely upon its character and requirements both present and future; but as a guide, the particulars of rolling-stock on some railways in newly-developed countries (the greater portion being in North America), have been tabulated from official reports. The following are the results:—

Miles open	140,756	
	No.	Average No. per Mile.
Locomotives	27,958	0·1986
Passenger vehicles	33,662	0·2389
Goods "	831,163	5·905

Taking the locomotives as 1, the passenger vehicles are as 1·2824, and the goods vehicles as 29·739.

The Table in the Appendix is interesting as showing that, whereas in general the number of passenger vehicles exceeds by about 50 per cent. the number of locomotives, the reverse is the case in the Southern and Western States of America, which are thinly populated, and that the total average is as above-stated.

The large number of goods vehicles 5·9 per mile, or a proportion of 29·74 goods to 1·282 passenger vehicles, shows how much heavier and more important in newly-developed countries is the

transport of goods than that of passengers; for the latter can ride or walk on bridle-paths, whereas the former, except at prohibitive cost, can only be conveyed on good roads, by water communication, or by railways.

Conclusion.

In consequence of the want of capital, it was customary in the United States up to the year 1860, if not later, to open railways at the least first cost, regardless of the large and expensive additions that would ultimately be required, as well as of the increased working-expenses entailed in the meantime. In the Author's opinion this policy was bad both in principle and practice; such additions can seldom, if ever, be made without inconvenience to the traffic, and at far greater cost than if executed in the first instance. The capital of American railways has from time to time been so largely increased, that the present great depreciation in value of the original stock is not surprising; and the Author considers that these works would not only have been better, but more remunerative, had they been constructed upon sounder principles and with greater stability.

APPENDIX.—PARTICULARS of ROLLING STOCK on SOME RAILWAYS in AMERICA and in the COLONIES.

Authority.	Name of Railway.	Miles open.	Locomotives. Number.	Passenger Vehicles. Number.	Goods Vehicles. Number.	Per Mile of Railway open. Locomotives.	Passenger Vehicles.	Goods Vehicles.
Poor's Manual of Railroads in the United States, 1884	New England States in 1853	6,323	1,819	3,055	40,212	0·2876	0·4831	6·359
	Middle States ,,	17,532	7,351	7,950	300,587	0·4193	0·4534	17·145
	Southern States ,,	18,866	2,514	2,276	53,427	0·1332	0·1206	2·832
	Western States ,,	70,345	11,418	9,663	340,079	0·1623	0·1374	4·834
	Pacific States ,,	7,486	721	903	14,356	0·0963	0·1206	1·918
Report dated 13th June, 1885.	Canadian Pacific	2,794	804	282	7,543	0·109	0·101	2·762 [1]
State Report 30 June, 1884	Intercolonial of Canada, Halifax to Quebec	847	163	241	4,348	0·192	0·284	5·133 [2]
Administration Report on Railways in India, 1883–84	Indian 5 feet 6 inches gauge	6,866	1,871	4,571	35,787	0·272	0·665	5·122
	India metre gauge	3,252	664	2,253	12,204	0·204	0·692	3·697
Administration Report, 1883, and subsequent information.	Ceylon Government	182	58	174	539	0·318	0·956	2·961
Annual Report for 1874	Mauritius ,,	66	27	87	331	0·409	1·318	5·005 [3]
,, 31 Dec., 1882	Queensland ,,	896	71	104	1,011	0·079	0·116	1·128 [4]
,, 31 Dec., 1881	New South Wales ,,	995	233	530	4,849	0·234	0·532	4·871
,, 31 Dec., 1882	Victorian ,,	1,355	228	456	3,951	0·168	0·336	2·916
,, 30 June, 1881	South Australia ,,	624	85	138	2,153	0·136	0·221	3·449 [5]
,, 31 March, 1883	New Zealand ,,	1,358	204	580	6,154	0·150	0·427	4·532
,, 31 Dec., 1882	The Cape ,,	969	227	399	3,632	0·234	0·412	3·748
Totals		140,756	27,958	33,662	831,163			
Average of totals						0·1986	0·2389	5·905
Proportion of totals			1·00	1·2824	29·739			

Remarks.—[1] Only partially open for traffic. [2] Opened about 1876. [3] Goods traffic heavy during crop season.
[4] Report states, "We have been extremely short of engines all through the year."
[5] Report states that more locomotives are required.

23 March, 1886.

SIR FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

(*Paper No. 2094.*)

"On the Construction of the Canadian Pacific Railway (Rocky Mountain Division) during the Season of 1884."[1]

By GRANVILLE CARLYLE CUNINGHAM, M. Inst. C.E.

WHEN the work of constructing the western division of the Canadian Pacific Railway was suspended for the winter in December 1883, the rails had reached a point about 4 miles short of the summit of the Rocky Mountains. This point is 960 miles west of Winnipeg, and 120 miles west of Calgary, the last station on the plains, where the line enters the mountains by the Bow Pass. From here two possible routes are available for further progress westwards: one following the Bow Pass to its summit, and thence descending by the Howse Pass into the Columbia Valley; the other diverging from the Bow Pass, reaching the summit of the Rocky Mountains at the commencement of the Kicking Horse Pass, and following this, entering the Columbia Valley at a point about 12 miles to the south of the mouth of the Howse Pass. The first route presented comparatively easy grades and curvature, but crossed the summit at 1,000 feet greater altitude, thus bringing the line into much deeper snow in winter; and it was 30 miles longer than the second. The second route, though of a lower altitude and shorter distance, would entail very heavy work at the head of the Kicking Horse Pass, in order to maintain equally good gradients. After considering the problem, the Directorate decided to adopt the shorter route by the Kicking Horse Pass, and to use a steep gradient at its commencement, in order to temporarily avoid the heavy work that will be required on the permanent line, and thus to effect the connection with the railway on the Pacific coast by the autumn of 1885.

[1] The discussion upon this Paper was taken together with that upon the two preceding ones.

ROUTE (Plate 5).

The route follows the valley of the Kicking Horse River, from its commencement near the summit of the Rocky Mountains, to its entrance into the valley of the Columbia River, a distance of about 45 miles. The Columbia Valley is from 6 to 8 miles wide, and is heavily timbered. It is the westerly limit of the Rocky Mountain range, which it divides from the Selkirk range. The general direction of the valley is north, for some 80 to 100 miles, when the river makes a bold sweep round the northern end of the Selkirks, at what is called "the Big Bend," and thence flows southwards, on the western side of the Selkirk range, to Oregon territory and the Pacific Ocean. The railway, entering the Columbia Valley at the point above mentioned, follows it northwards for a distance of about 30 miles, until the mouth of the Beaver River, flowing out of the Selkirks, is reached. Here the line turns west, ascends to the summit of the Selkirks by the Beaver Valley, and thence descends, by the valley and cañon of the Illecilli-waet, to the second crossing of the Columbia River. From the second crossing it ascends the Eagle Pass, through the Gold range, and passes by the valley of the Shoo-swap Lakes to Kamloops, to which point the rails from the Pacific coast have been laid. The distances, measured from the summit of the Rocky Mountains, and the altitudes above the sea, at various points along this route, are as follow:—

	Distance.	Altitude.
	Miles.	Feet.
Summit of Rocky Mountains	..	5,296
Mouth of Kicking Horse Pass	44¼	2,539
First crossing Columbia River	62	2,521
Mouth of Beaver River	73¾	2,340
Summit of Selkirks	94¼	4,300
Second crossing Columbia River	139½	1,600
Kamloops	270	..
Port Moodie (tide water)	501	..

GEOLOGICAL SYSTEM.

The geological system through which the line passes is the Lower Carboniferous. At the upper portion of the Kicking Horse Pass, hard crystalline limestone is found, in several instances of a quality so pure and homogeneous as to form marble of some commercial value. Lower down the pass, the shales of the system appear in every variety; sometimes dark hard slates, sometimes soft laminated clays.

With the exception of the hard limestone at the head of the Kicking Horse Pass, none of the rock, between that point and the mouth of the Beaver, is of quality good enough for building purposes. Generally the mountains rise directly from the valleys, at a very steep slope, without any intervening foot-hills, and continue with an even inclination to their summits, often from 5,000 to 6,000 feet above the valley. The lower half is covered with a comparatively thin layer of soil, resting on the smooth and slippery surface of the shale, and bearing a thick growth of timber and underbrush; the upper half is bare, affording, by its rugged surface, a gathering-place for the heavy snows that fall in winter. The consequence of this mountain-formation, combined with the friable and treacherous shale rock, is that "land-slides" are no unusual occurrence. The wash of a stream at the mountain's base wears away the clay bank, and the support for a large stretch of soil on the steep mountain-side being thus removed, a slide takes place, and acres of ground are left stripped of the covering soil and trees; while snow and ice, gathering on these steep mountain-sides, are liable to descend in spring, or during a winter thaw, with great force, bringing down boulders and trees in their course.

Climate.

The climate has much to do with the difficulties of railway construction in any country. In 1884, in the district under consideration, snow lay deep in the bush at the summit of the Rocky Mountains into the month of June. The Kicking Horse Lake, at the head of the pass, was not free from ice until the middle of the same month. Rain fell almost incessantly during July and August, which, combined with the melting snow on the mountain-tops, kept the rivers and streams in high flood. On the 28th of September, 1884, a depth of 4 inches of snow fell in the valley at the summit, and by the middle of the following month the Kicking Horse Lake was again frozen over, to remain so throughout the winter. In the Columbia Valley, owing to its lower altitude, a better condition of things prevailed. The snow was all gone by the end of March, and did not again fall, to remain on the ground, until the middle of December. Between these extremes the climate varied with the altitude, between the Rocky Mountain summit and the mouth of the Beaver. In the winter of 1883–4, a register of the temperature was kept in the Columbia Valley at the mouth of the Kicking Horse River. On the 30th of December, 1883, the thermometer registered $-40°$ Fahrenheit, and on the 9th and 10th

of February, 1884, a temperature of $-38°$ was recorded. In the interval of time between these two lowest extremes, the average temperature was $-12°$. During the winter of 1884–5, in the Columbia Valley, the temperature fell to $-42°$ on the 24th of December, and from the 15th of the month up to that day the average was $-26°$. At the summit of the Rocky Mountains, during the same period, a temperature of $-48°$ was registered. It will be easily understood, with such a low temperature as this, how much difficulty may be caused by ice piling in the rivers about bridge-piers; by springs that force their way out of the sides of cuttings, and freeze as soon as they begin to flow; and by accumulations of ice that form on the mountain-sides, until they fall by their own weight.

Natural Products.

The natural products of the district lying between the Rocky Mountain summit and the mouth of the Beaver, capable of use in railway construction, are very few. Throughout the whole length, timber is to be had sufficient for ties (sleepers) and temporary bridges, trestles, and culverts. At the summit of the Rocky Mountains, on the margin of the Kicking Horse Lake, a steam saw-mill was erected by the end of July, for cutting up the timber growing in the immediate neighbourhood into bridge- and trestle-timber. This timber is chiefly white spruce, unusually sound, and, though not of equal strength with the ordinary American pine, is admirably adapted to the purpose for which it is required; being obtainable easily, and in large quantities, it was of much value in expediting the work. Further down the pass, better and larger timber was got, and in the Columbia Valley fine specimens of the Douglas pine (*Pina ponderosa*)—a very hard and strong wood—were used in bridge- and culvert-building. Everything else that was required on the work had to be brought in from the East for very long distances. The thick growths of moss on the ground, produced at the summit, doubtless, by the continuous wet weather during the period of vegetation, prevented any growth of grass that might be used as fodder for horses or cattle; and the totally uninhabited state of the country was a sufficient reason for the absence of artificial grasses or cereals in the Columbia Valley, where they might grow if cultivated. The importation of food for horses and cattle, as well as for the men employed, was a serious undertaking, and one which necessarily added much labour to the work.

General System.

The following brief description is necessary in order to understand the manner and the difficulties of carrying on the work. In the first place, it was necessary to construct a wagon-road along the general line of the intended route, so that contractors with their men, plant and material, might be placed on the work at various points; and for bringing in provisions and necessaries. Hitherto the passes and valleys traversed by the surveyed line had been reached only by narrow trails, affording sufficient, though often dangerous, accommodation for pack-ponies, but inadequate to the requirements of railway work. The construction of this road was pushed on as rapidly as possible in advance of the work, in many places merely enough being done, in the way of clearing timber, to admit of the passage of wagons through the bush. Contractors were then brought in and established in their camps on the portions of the line allotted to them. The contracts varied in length from 1 mile to 4 or 5 miles, according to the nature of the work and the capacity of the contractor. As each portion was finished, the contractor was moved on further to the front; and in this manner a stretch of about 40 miles in advance of the end of the track was kept constantly in hand. As the grading progressed, track-laying was continued, and the end of the track steadily advanced. The company's main stores were established at Laggan, about 6 miles east of the summit of the Rocky Mountains. Here an ample stock was kept of everything that could be required by the contractors or their men; such as tents, tools, wagons, harness, provisions, clothing, hay, oats, &c. These were sent out by rail to the "End-of-track store," a movable store, maintained in cars, and advanced every few days as the track was laid. From this point the goods were conveyed by wagon to the various camps. The heavy traffic which the roughly constructed wagon-road had to bear, in carrying forward supplies for four thousand men and one thousand two hundred horses or mules, combined with the copious and continuous rains, so cut up the road, that at times, and in many places, it was almost impassable. A weight of 1,000 lbs. constituted a load for a pair of horses, while 12 to 15 miles was the extent of a day's journey. The difficulty in maintaining supplies in sufficient quantities over such a road was not small, and the attendant expense was very great. The cost of conveying stores to a point 40 miles beyond the end of the track was 8 cents. (4*d.*) per lb., and this, when applied to hay and oats, made horse-food an expensive item. The opening

out and construction of the road was begun at the summit in the middle of April, and by the latter part of the same month, contractors were set to work on the temporary line at the head of the Kicking Horse Pass.

CURVES AND GRADIENTS (Plate 5).

Up to the summit of the Rocky Mountains the curves and gradients have been light; the latter not exceeding 40 feet to the mile, except in one or two instances. From this point, however, the descent of the valleys and rivers to the west is so rapid, that it was necessary to adopt a heavier maximum gradient, in order that the line might be able, approximately at least, to follow the natural descent of the ground. The gradient fixed upon as a maximum is 2·2 feet per 100, or 116 feet to the mile, or 1 in 45·45. This gradient has been exceeded only in the instance of the temporary line, at the beginning of the Kicking Horse Pass. The descent in this pass, at its commencement, is very steep; the river falls 1,100 feet in 3½ miles. To follow such a descent the gradient would have been impracticable for a railway: while, on the other hand, with the 2·2 gradient the line would have been so high up on the mountain side, and so many miles of heavy and difficult side-hill work would have been required before it could reach the valley, that much delay would have been occasioned in the work further to the west. It was therefore decided to make the descent of the upper portion of the pass on a temporary line, with a gradient of 4·50 feet per 100, or 237 feet to the mile, or 1 in 22·22. The temporary line begins at a point about 4 miles west of the summit. At first there is ½ mile on a gradient of 3·50 per 100; this is followed by 3¼ miles of the 4·50 gradient, after which 3½ miles of the 2·2 gradient takes the line down to the base of the mountain and the flats of the river. This heavy gradient winds down the mountain side, with curves whose maximum deflection on 100-feet chord is 10° (573-feet radius). Though so unusually severe, the practical working has shown that a large traffic can be successfully carried over it. Details are given further on of the working of this gradient.

In every instance where curves occur in conjunction with the maximum gradient, the grade was equated for the curve so that the resistance to traction would not be greater on the curved than on the straight part of the line. The equation used was 0·3 of a foot rise per 100 feet for each degree of curvature; so that on a 10° curve, the rise per 100 feet was reduced 0·3 per foot. A rise

of 0·3 per foot in 100 is a gradient of 1 in 333, which would develop a resistance to traction of 6·73 lbs. per ton; this, therefore, is the allowance given as the equivalent in resistance of a 10° curve (573-feet radius); and close observation on the heavy grade on the temporary line showed that this was very near the truth. The locomotive, when ascending with a full train, had a tendency rather to gain, than to lose, speed on the curves. It should be stated, however, that all cars and engines were mounted on bogies.

Grading.

The cuttings are taken out to a width of 22 feet in the bottom, with a side-slope varying from ¼ to 1 to 1½ to 1, according to the nature of the material. The hardest rock encountered was that on the temporary line. It is a crystallized limestone. Owing to the impossibility of bringing machinery over such a road as has been described all drilling was done by hand. In the hardest of the rock two strikers and one holder could drill only 9 lineal feet in ten hours' work, the hole being 1½ inch in diameter. The amount usually accomplished in rock of average hardness was from 16 to 18 feet in that time. The explosive used was dynamite, generally of 75 per cent. strength, which was made at a factory erected by the company at the Kicking Horse Lake. The explosive was discharged sometimes by time-fuze, and sometimes by electricity. Lower down the valley, where shale rocks were encountered, the action of dynamite was found to be too quick, as its force was spent between the layers of the rock and through fissures, and better results were obtained from black powder. In some few instances, in rock-cuttings near the dynamite factory, pure nitro-glycerine was employed with good results; but the use of this was not permitted on other parts of the line, owing to great danger attending its transportation.

The width of the banks on the top is 14 feet. They were made, whenever practicable, from the excavation hauled out from the cuttings. But a considerable portion of the line, on the flats of the Kicking Horse River, for example, and in the Columbia Valley, consists of a light bank, averaging 3 feet above the general level of the ground, formed by material collected with "scrapers" from the sides.[1]

Where the material has to be taken out of a cutting to form a bank at some little distance, wheel-scrapers are used. These are

[1] Minutes of Proceedings Inst. C.E. vol. lxxvi. p. 273.

large sheet-iron scoops of about ⅓ cubic yard capacity, mounted on wheels. By a simple arrangement of a crank upon the axle, worked by a hand-lever, the wheels can be raised, so that the body of the scraper drags on the broken-up soil, and fills by the traction of the horses. When full, a pressure of the lever again brings the wheels into action, and the load is run out and "dumped" in position. Wherever possible, ploughs were used to break up the material in the cuttings, so that it might be taken out by scrapers.

The following quantities were taken out on the different divisions of the line:—

From the summit of the Rocky Mountains to the mouth of the Kicking Horse River—44¼ miles: Solid rock, 256,834 cubic yards; loose rock, 115,371 cubic yards; earth, 988,255 cubic yards; hard pan, 136,457 cubic yards. Total, 1,496,917 cubic yards. This is exclusive of the excavation in tunnels: it gives an average quantity of 33,806 cubic yards per mile.

From the mouth of the Kicking Horse to the first crossing of the Columbia River—17¾ miles: Solid rock, 646 cubic yards; loose rock, 1,011 cubic yards; earth, 341,336 cubic yards; hard pan, 18,990 cubic yards. Total, 361,983 cubic yards. The average quantity on this division is 20,393 cubic yards per mile.

On the succeeding 11 miles from the First Crossing to the mouth of the Beaver, the average quantity was 27,500 cubic yards per mile.

Tunnels.

On the length of line constructed—73¾ miles—there are seven tunnels. Their positions, length, and general nature, are as follow:—

	Distance from Summit.	Length.	Remarks.
	Miles.	Feet.	
No. 1	8	130	On temporary line; solid rock.
„ 2	33¾	470	Clay; timber lined.
„ 3	40	337	Rock.
„ 4	40½	298	„
„ 5	42½	360	Part rock and part soft; timber lined for 200 feet.
„ 6	63½	97	Rock; part lined.
„ 7	67¼	460	Gravel and rock; part lined.
Total		2,152	

The general section adopted for tunnels is 22 feet in height, by 16 feet wide. This gives about 12 cubic yards of material per

lineal foot. The great height, as compared with European tunnels, is necessary in order to meet the requirements of the Canadian Railway Act, which specifies that every permanent structure spanning a railway line, shall be of such height as to give a clear space of 7 feet between the lowest part overhead, and the top of a box freight-car; so that brakemen may not be endangered when on the roof of a car, in the execution of their duty.

Tunnel No. 1 is situated immediately at the foot of the 4·50 per cent. grade, on the temporary line. The material is hard crystalline limestone, much fissured and broken. The progress was 6½ feet per week at each face. Gangs were kept at work night and day. All drilling was done by hand, and the explosive used was dynamite.

Tunnel No. 2 is through a lofty spur, composed of blue clay, hard packed gravel, and boulder-drift. The blue-clay seam at the eastern mouth of the tunnel is about 20 feet in thickness, resting upon fine sand, and supporting an overlying mass of boulder-drift, having fine veins of sand interspersed. It would scarcely be possible to find material more treacherous than this. Streams and springs from the mountain slope make their way down through the soil, and working out in the veins of sand, and between the boulder-drift and the blue clay, cause deep excavations, which result in sudden and disastrous "slides." Work was begun early in June, and on the 23rd of July a heavy "slide" took place at the eastern breast of the tunnel, tearing away about 30 lineal feet of the timber lining, and bringing down about 15,000 cubic yards of material, which completely blocked the mouth, entailing a long delay. Again, in the beginning of October, when the piercing of the hill was completed, and the track about to be laid through, a second "slide" at the same end of the tunnel, brought down about 9,000 cubic yards.

Throughout its whole length, this tunnel is lined with timber. Each section of the frame of the lining consists of two upright posts 14 feet in height, 12 inches square in cross section, standing on a transverse sill, and supporting a longitudinal cap: from this cap spring two inclined pieces, straining against a central straining-piece in the roof of the tunnel 7 feet in length. These sections of the frame were put in at 3 feet apart from centre to centre. At the back timber-lagging was closely packed in, 6 inches square, in lengths of 3 feet. The quantity of timber used in the lining was 780 feet board measure per lineal foot. The timber was all obtained from the bush in the immediate

neighbourhood, and was hewn with the axe to the proper dimensions.

When the tunnel was opened through, it was found that the action of the air on the blue clay at the eastern end caused it to swell, and the tremendous pressure thus exerted crushed the timbers of the lining in the roof. The track was laid through the tunnel on the 20th of October, 1884. All the work in connection with the piercing and lining was done by Messrs. Corry Bros., of Wisconsin. This tunnel is on a 9° curve (636 feet radius).

Tunnels No. 3 and 4 are pierced through slate shale. Work was begun in July and finished in September. Messrs. Muir Bros., of St. Paul, Minnesota, were the contractors. The following are the particulars of the work:—

Average progress at every face in twenty-four hours, working eleven-hour shifts, 3 feet 3 inches; average depth of hole drilled (all by hand) in heading, 3 feet 6 inches; diameter of hole, 1½ inch; average quantity of material moved per man employed in twenty-four hours, 1·625 cubic yard. Each shift at each face consisted of one foreman, nine drill-men, one dump-man, two drivers, and eleven shovellers.

The fifth tunnel is pierced partly through gravel and partly through shale rock; that part which is through gravel is timber-lined, in the same manner as tunnel No. 2. The sixth tunnel is only 97 feet long, and timber-lined for 30 feet. The seventh tunnel is on a 10° curve (573 feet radius); is 460 feet in length, and is timber-lined for 150 feet. The material through which it is pierced is partly gravel and partly hard shale rock. Work was begun on it at the end of July, and it was finished in time for the track to be laid through it in the middle of December.

Bridging.

As might be expected on a line traversing deep valleys and ravines, the amount of bridging constructed is extensive. There are nine crossings of the Kicking Horse River, six of these crossing within a distance of 12 miles. Such a fact as this gives most concisely an idea of the winding and difficult nature of the pass through which the line is carried. There is one crossing of the Columbia River,[1] and numerous crossings of smaller rivers and streams.

All the bridges and trestles constructed during the season

[1] Minutes of Proceedings Inst. C.E. vol. lxxxii. p. 345.

were of wood. Most of the timber was obtained in the district, the main-posts, caps, sills, and such pieces being hewn on the spot; while the floor-timbers, deck-material, and lighter pieces, were sawn at the mill on the Kicking Horse Lake. The heavy chord-sticks, principal truss-members, and track-stringers, were of sawn white pine imported from the east, as was also the oak used in trusses. One general design was employed for trestles: the openings were of the uniform width of 15 feet from centre to centre. Piles, usually four, were driven in a row at the position of each "bent." When the rail-level was not more than 8 to 10 feet above the ground, these piles were cut off at from 5 to 7 feet, and a cap, consisting of a timber of 12 inches cross-section by 14 feet long was drift-bolted on to the top of them. From cap to cap the rail-stringers, consisting of pieces 9 inches by 15 inches by 16 feet long, or 6 inches by 15 inches by 16 feet long, spanned the intervening space of 14 feet. The stringers were placed so that their ends lapped past on the caps. For one span, three 6 inches by 15 inches pieces were placed under each rail; for the next span, two 9 inches by 15 inches pieces, and so on alternately. In this way a good bearing was obtained on the cap, the stringers were in the best position to support the rail, while in each span there was the same amount of timber. At the outer ends of the caps, additional 6 inches by 15 inches stringers supported the ends of the floor-timbers. These latter were 6 inches by 8 inches by 14 feet, and were placed transversely on the stringers at 15 inches from centre to centre. To these the rail was spiked. When the height of the rail-level above the ground exceeded 10 feet, or thereabouts, a "trestle-bent" was put in to support the cap. The piles were then cut off at the level of the ground, and a sill 12 inches square in section was drift-bolted down to them; on this sill were erected two vertical and two battering posts 12 inches square, and of the necessary height supporting the cap; at the meeting place of the posts with the cap, or sill, the junction was made secure by a mortise and tenon-joint, and the posts were further secured by cross-bracing of 3-inch plank. When the height of the trestle exceeded 35 feet, an intermediate sill was inserted, carrying a fresh set of vertical and battering posts, and thus the structure was carried up by "lifts" or storeys of 20-feet height each, to the required altitude. In the instance of the trestle crossing the Otter Tail Creek, this altitude exceeded 100 feet above the ground.

The general system of building trestles and bridges was as follows:—After the ground had been cleared of trees and prostrate

timber, the piles were driven in position by the pile-driving gang. The main-timbers, such as sills, posts and caps, were hewn in the immediate neighbourhood, framed and erected ready to receive the track-stringers. When the track, as it was being laid, arrived at such a structure, a car, laden with the requisite number of stringers and floor-timbers, was run forward to the extremity of the rails, unloaded, and the pieces placed in position by a gang of bridge-men. This generally involved some delay to track-laying, but by proper organization and promptness the delay was small. It could usually be arranged that any large structure could be completed by the bridge-men at night. It was impossible to transport heavy bridge-timbers by wagon over the wagon-road, as had been done on the prairie sections of the line.

The Howe truss, in spans varying from 100 to 150 feet, was chiefly used. The lower six crossings of the Kicking Horse River are from 200 to 300 feet in width, requiring two trussed spans. What has been said in regard to the impossibility of bringing forward heavy timbers by wagon for trestles, applies with greater force to the long chord-timbers, iron rods and castings needed for trusses. To obviate the delay to track-laying, which would have occurred had the truss material been run forward to the end of the track at each bridge, the truss erected, and the track then laid across, it was deemed expedient to bridge the river by temporary pile-structures at the various points, and to erect the trusses at greater leisure, after the material had been brought forward by the train, and the track-laying passed on. This plan was adopted for all the main bridges, except the second crossing of the Kicking Horse River, and the crossing of the Otter Tail Creek. The former is of 150 feet span, and crosses a chasm in the upper part of the valley 75 feet in depth; while the latter is of 100 feet span in the centre of a 500-feet length of trestle, and is 112 feet above water-level. In those places it was unadvisable to put in temporary work, and the permanent trusses were therefore erected in the first instance.

The piers carrying these trusses were formed of timber crib-work filled with stone. The greatest depth of the water, in the ordinary state of the Kicking Horse River, was not more than 6 feet where the piers were placed. The depth in the Columbia River was 15 feet. The total length of bridging and trestle-work from the summit to the first crossing of the Columbia River (62 miles) is 8,039 lineal feet.

The piles were selected from trees growing in the neighbourhood, and were required to be not less than 8 inches in diameter at the

small end, and 12 inches in diameter at the butt when sawn off. They were driven under a hammer weighing 2,000 lbs., and the driving was continued until there was not more than ½-inch penetration under a blow of this weight falling 25 feet. Five piledrivers were at work during the latter part of the season. Including the delay of moving and setting up the machine, which is always considerable, the average work for each driver was ten to fifteen piles per day, in structures having about forty piles, driven an average depth of 10 feet into the ground.

Track-laying.

A single line of track has been laid. The rail is steel, of the Sandberg pattern, with angle-plate joints, and secured to the ties (sleepers) by spikes. The weight of rail to a point 3½ miles west of the summit of the Rocky Mountains is 60 lbs. to the yard. From here through the Kicking Horse Valley, for a distance of 41 miles, the gradient and curves being severe, a rail of 70 lbs. to the yard was laid. In the Columbia Valley, to the crossing of the river (18 miles), the 60-lb. rail was adopted, and from this point on to the mouth of the Beaver (12 miles), through the Columbia Cañon the 70-lb. rail. The angle-plate connection, which has recently been adopted in Canada and the United States in preference to the old fish-plate joint, makes a very rigid and perfect track. The weight of the angle-plate joint is rather more than double that of the fish-plate, being 5·66 tons per mile with 30-feet rails, as compared with 2·51 tons. Ties were laid at the rate of three thousand to the mile, or 1 foot 9 inches from centre to centre. They were 8 feet long, 6 inches thick, and not less than 6 inches in the face, hewn on two sides. They were made from timber growing in the mountains, chiefly spruce and jack-pine.

Track-laying was begun in June, but was carried on slowly, pending the construction of the temporary line, on the heavy grade, at the head of the Kicking Horse Pass. By the 18th of June it had reached only to the first tunnel, 8 miles west of the summit. From this point, however, it was continued more evenly and steadily. The Columbia Valley was entered on the 10th of November, the Columbia River crossed on the 1st of December, and the mouth of the Beaver, at the end of the Columbia Cañon, was reached on the 26th of the same month. Here the work was suspended for the season. The distance from the summit is 73¾ miles, and the total distance track was laid, 75¾ miles.

The work was done by a gang averaging ninety men. They were carried along in a train of cars, fitted up with sleeping and boarding accommodation, so that they were always close to their work, since the train was kept at the end of the track. As the rails for laying were run to the front, they were unloaded immediately to the rear of the boarding-train, this train was pulled back, and the fresh rails, with the requisite ties, were placed on light push-cars, and hauled forward by horses to the last pair of rails in position. From this the ties necessary for a length of rails were laid out, a pair of rails was placed in position, and the car run forward, the same operation being repeated for the next pair of rails. Men coming behind put on the angle-plates, and spiked the rails to the ties. The greatest length of track laid in one day was 1·4 mile. This "record" is very small as compared with the work done on the prairie in the summer of 1883, when 6·3 miles of track were laid in one day; but on the mountain division it was impossible to obtain the same assistance from teams, conveying material to the front alongside the track, as had been given on the prairie section, and all the work of laying had to be carried on from the cars.

DYNAMITE FACTORY.

A dynamite factory was erected on the bank of the Kicking Horse Lake for manufacturing the explosives used on the work, so as to get rid of the danger attendant upon their transportation from long distances east by rail. The acid and glycerine were brought by train to the factory, which was immediately alongside the track. In the first instance, charcoal, made from the trees in the neighbourhood, was used as the absorbent; but its absorbing powers were not sufficient for the high grade of powder, while the charcoal-gas evolved on explosion rendered the air in tunnels very bad, and delayed the men at work. Latterly recourse was had to wood-pulp, brought from the east. Necessarily a much larger quantity, by weight, of raw material was brought in than would have been the case had the manufactured article been purchased from some eastern factory; but the risk of carrying large quantities of high per cent. dynamite 1,500 or 2,000 miles by rail, as well as the high rate of freight exacted by railway companies for its conveyance, more than counterbalanced the freight charges on the additional weight of raw material.

The quantities entering into the composition of 100 lbs. of dynamite of 75 per cent. strength, are as follow:—

Raw material.		Dynamite.	
Lbs.		Lbs.	
37½	glycerine.	75	nitro-glycerine.
300	nitric and sulphuric acid.		
25	wood-pulp.	25	wood-pulp.
362½		100	

It will thus be seen that the weight of the raw material is more than three and a half times that of the manufactured article. More than 90 tons of dynamite were made at this factory during the season, and forwarded by rail and wagon where required, without accident. The factory has now been moved from the Kicking Horse Lake, and re-erected in the Columbia Valley.

As a gradient of 1 in 22 with sharp curves on the 4 feet 8½ inches gauge is not common, some particulars in regard to its working may not be without interest. The locomotives were without any special adaptation to such a grade, being the ordinary engines of the Canadian Pacific Railway Company. They are mostly built at the Baldwin Locomotive Works of Philadelphia, and had two pairs of driving-wheels coupled, the weight on the drivers being about 26 tons, and the total weight of the engine 33 tons; the weight of the tender was 15 tons. Some were fitted with the Westinghouse brake, while others had only hand-brakes. Where the steam-brake was attached, it was used only on the tender, and was not applied to the cars. The diameter of the driving-wheels varied from 4 feet 8 inches to 5 feet. Two such engines were always worked together, both in descending and in ascending the gradient, one at the head of the train, the other at the rear. The train in descending usually consisted of from twelve to fourteen loaded cars, averaging 26 tons gross weight each; the ascending train consisted of from eight to twelve empty cars, averaging 10 tons weight each. The speed during the descent never exceeded 4 miles an hour, while in the ascent, with the rail in good dry condition and a moderate train, it was often at the rate of 6 to 8 miles an hour on the steep part of the grade. It was necessary to descend slowly, because if the train attained a speed much greater than 6 miles per hour, there was considerable danger of its getting out of control. Two "runaways" took place, while track was being laid, which demonstrated the necessity for care and extreme watchfulness. Since, however, the line has been used for bringing forward the company's supplies and material, a

large quantity of freight, embracing provisions, supplies, rails, timber and dynamite, has been brought down this grade in safety. In the two months of October and November 1884, sixteen hundred and twenty-two loaded cars were taken down the grade, and fifteen hundred empties brought up; and this by four ordinary light locomotives, such as are in use in other parts of the line.

It is the intention of the company to use large and powerful consolidated engines on this part of the road, during the construction of the railway to the west. Two such engines have been built by the Baldwin Locomotive Works, and in January (1885) one of them was tried and tested on the grade, with very satisfactory results. This single engine took up a train of twelve cars, weighing 280,850 lbs. at a speed of 4¼ miles per hour. It has four pairs of 4-feet driving-wheels coupled; the cylinders are 20 inches by 26 inches; the steam-pressure in the boiler is 150 lbs. per square inch. Two trials were made, the first on the 20th of January, the second on the 28th. The first trial was with the engine burning wood, when difficulty was experienced in keeping up steam. The second was carried out with coal as the fuel, and as maintenance of steam was then perfect, the results of that test are given:—

TEST of CONSOLIDATED ENGINE on 4½ PER CENT. GRADE (1 in 22·2) in the KICKING HORSE PASS on the 28th of JANUARY, 1885.

Thermometer, 25° Fahrenheit. Rail, clean and dry.

	Lbs.
Weight of engine on drivers	102,000
,, ,, on front truck	14,000
,, tender when full	50,000
Total weight of engine and tender	166,000
Weight of train (twelve cars)	280,850
Total weight of engine and train	446,850
	Feet.
Length of grade	17,000

Time of ascent, forty-five minutes. Speed, 4·29 miles per hour. Steam-pressure at foot of grade, 126 lbs. per square inch; do. at head, 140 lbs. Consumption of coal, 2,676 lbs.; do. of water, 1,498 gallons; consumption of water per minute, 33¼ gallons. Fuel consumed per gross ton moved 1 mile, 4·16 lbs. Resistance on grade per ton, 110 lbs. Total resistance of locomotive and train, 21,941 lbs. Equivalent in foot-lbs. in ascending grade, 372,997,000. Foot-pounds per 1 lb. of coal consumed, 139,386.

The adhesion developed in the engine was two-ninths of its weight on the driving-wheels. The coal used was not of the best quality, 1 lb. evaporated only 0·56 gallon of water.

There are several 10° curves (573-feet radius) of short length on the grade, but the grade is equated for the curves, and the resistance on them was no greater than on the straight parts. In descending the working of the engine was very satisfactory, and no difficulty was experienced in controlling a train of fourteen loaded cars when moving at 8 miles an hour. The engine is fitted with the Westinghouse steam-brake, which is applied to the driving-wheels and the wheels of the tender. With two engines such as this a large traffic can be successfully worked on this gradient.

A telegraph line has been constructed along the route of the railway.

The uniform rate of wages paid for common labour was \$2 (8*s*.) per day of ten hours, and the men were charged \$5 (£1) per week for board.

On a work such as has been described, carried on in an entirely undeveloped and uninhabited country, and at a distance of some 200 miles from any of the established institutions of civilized man, it was necessary to make provision for the wants and needs of the contractors and labourers in every respect. A bi-weekly mail service, by means of pony couriers, was established along the whole length of the route on which contractors' camps were placed, and beyond to the outlying camps of the surveying parties. This mail service was independent of the Government postal service, which did not extend beyond the end of the track-store. At this point the Government post-office was maintained in a car fitted up for the purpose, and which was moved on from time to time as track-laying progressed.

An efficient staff of doctors was maintained, and hospitals for the treatment of the sick and injured were erected at convenient points. All men employed were charged 75 cents. (3*s*.) each per month as medical dues, and for this all medicines, doctor's attendance, and hospital treatment, were given free of further charge.

A detachment of the North-West Mounted Police, numbering twenty-five men, was told off for duty along the line of railway, and this small body of men, under the command of Captain S. B. Steel, was successful in maintaining law and order among the heterogeneous population, in which were representives of almost every European nation, numbering over six thousand labourers and camp followers.

The work of construction has been carried on during the winter, and at the present time (February 1885) contractors are spread over the route, from the end of track to the second crossing of the

Columbia River, a distance of 65 miles. It is confidently expected that the junction with the rails from the Pacific Coast will be effected by November.

The whole of the works, as well as the preliminary and final surveys, have been carried on under the direction of Mr. James Ross, the Chief Engineer and Manager of Construction.

The Paper is accompanied by a small scale-map and profile, showing that portion of the line which was completed in 1884, from which Plate 5 has been prepared.

Since the foregoing Paper was written, the construction of the Canadian Pacific Railway has been completed. On the 7th of November, 1885, the last rails were laid, and connection was effected with the track from the Pacific Coast at a place about 30 miles west of the second crossing of the Columbia River. During the season of 1885 the work was pushed eastwards from Kamloops to meet that being carried westwards across and beyond the Selkirk range. Thus in a period of barely eighteen months the line has been constructed from the summit of the Rocky Mountains to Kamloops, a distance of 270 miles, through a most rugged and difficult country, where, before the advent of the railway, there were no other means of communication than those afforded by a rough pack trail.

Discussion.

Mr. Shelford. Mr. W. SHELFORD observed that last year he had occasion to travel across Canada and British Columbia, returning by the United States, and he had paid considerable attention to the American system of railway construction. He had met Mr. Cuningham, and had, as the result of that meeting, become a sort of sponsor for his Paper, Mr. Cuningham himself being at the present time snowed up in the Selkirk Mountains, British Columbia. The works upon the Rocky Mountain section of the Canadian Pacific Railway were tolerably familiar to Mr. Shelford, and he could bear out all that Mr. Cuningham had said with regard to them. But since the Paper was written, the line had been extended further west through a more difficult country, where the works were of a more important character, including one work which might be said to be the highest timber structure in the world—a viaduct over a place called Stoney Creek, which had a centre pier 280 feet high, upon which were truss girders 30 feet deep, making a total height of 310 feet. It was admirable in design and in execution. The rapidity with which that and similar works had been constructed was remarkable. Close by there was a trestle viaduct, with a span in the middle of 150 feet. It was 1,100 feet in length and 156 feet high, and in three months from the time of getting the first timber for it in the forest adjoining the first train passed over it. He had brought photographs of some of the works for the inspection of members. Among them was one bridge mentioned by Mr. Cuningham on the length described in his Paper—a trestle viaduct over the Otter Tail Creek, upwards of 100 feet high. With regard to track-laying, Mr. Bell had read a short Paper describing the track-laying on the Canadian Pacific Railway,[1] Mr. Cuningham had described the track-laying upon the division under his charge, but he had omitted what appeared to be the key to the position. The rails were brought up by a train as near as possible to the end of the track, each car in the train being loaded with a certain quantity of rails and a corresponding quantity of fastenings. The cars were unloaded by hand by the side of the track, and then the train was brought back. There was only a single track to work upon, and there were two or four trolleys (depending on the speed at which the operation was carried forward), which were worked

[1] Minutes of Proceedings Inst. C.E. vol. lxxi. p. 383.

by horses. Those trolleys were loaded one at a time with rails Mr. Shelford. and fastenings. One of them was pulled forward to the front and unloaded by hand. Meanwhile another was being loaded, and when it was necessary for them to pass, the trolley in front, which was by that time empty, was tipped on its side by twelve men, the loaded one being pulled past it. That he considered to be the key to rapid track-laying. He had met some of the best track-layers in Canada, and they all agreed as to that point. The Engineer-in-Chief of that part of the line, and indeed of all the most difficult parts, was Mr. James Ross. The maximum speed in track-laying attained on the Canadian Pacific, in the prairie section, was 4½ miles per day, and the average, in August 1882, was 3¼ miles per day. In the Selkirk Mountains and the Rocky Mountains the speed was from 1¼ mile to 2½ miles per day, depending entirely upon whether or not the sleepers were provided beforehand. If the sleepers were cut out of the forest and laid in advance of the rail, the speed of the track-laying was 2½ miles; if they were brought from the rear it was 1¼ mile per day. It might be interesting to compare the quantities of earth-work given by Mr. Cuningham with the quantities used in England. The total quantity on the 73 miles described in Mr. Cuningham's Paper was about 2,000,000 cubic yards. A line which Mr. Shelford had just completed, about the same length, the Hull and Barnsley, which was constructed with considerable rapidity, and was considered a good example of rapid construction in this country, contained about 6,000,000 cubic yards, or three times the quantity. Comparing the Canadian Pacific Railway with the Hull and Barnsley, one-third of the quantity of earth-work was done in one-fourth of the time. With regard to cost, he believed that the standard price of earth-work in Canada and in the United States was about the same as in England, 1*s.* per cubic yard, notwithstanding that the wages of the navvies in Canada and the United States were $2 (8*s.* 4*d.*) a day, more than double the amount paid in England. The result was brought about by the large use of horses. Horses were used to plough up the ground, and then scrapers were employed to get it into position. The leads were very short; in fact the ground was generally scraped up from the side and put into bank. The leads were much more expensive than in this country. Notwithstanding all those appliances and the small extent of labour, the amount of plant appeared to be exceedingly small. He never saw a tip-wagon or a contractors' temporary rail. Indeed, there was scarcely any plant about the place. He was sure that the amount spent on the line for plant was nothing like £500 per mile, whereas on the Hull

Mr. Shelford. and Barnsley line the amount reached £2,000 per mile. The cash cost of that length of the Canadian Pacific was about one-fourth the cash cost of the Hull and Barnsley. He did not think there had been any iron bridges on that length of the Canadian Pacific, but up to that point there were a great many. It was well known that Englishmen made the first iron bridges in Canada, notably the Victoria Bridge over the St. Lawrence, designed by Mr. Robert Stephenson. It was equally well known that Englishmen did not now make iron bridges for Canada at all. They were all designed and built by Americans. Englishmen had lost the trade entirely, simply because they had not kept pace with the times. He ventured to think that the Board of Trade rule was somewhat to blame on that point. He thought that a definite factor of safety, such as 5 tons per square inch for iron, tended to discourage the manufacture of superior metal, and did not tend to encourage good work, because the manufacturer was only called upon to provide an inch of iron of inferior quality for every 5 tons theoretical strain, and very moderate work was good enough. He regarded the rule as wrong in principle, and he hoped, as the days of steel were approaching, that it would be altered. Although in Canada there was an admirable system of Government inspection, the inspector living on the line like the resident engineer, there was no such rule. In consequence it was everybody's interest and desire to produce a good bridge with the best possible materials and workmanship, the object being to lighten the weight and at the same time to pass the heavy tests which were applied there—quite as heavy as those applied in England. He had spent some time at the Dominion Bridge Company's works at Lachine, near Montreal, the best and most modern-equipped works on the Continent of America. Plate-bridges were made there for 60-feet span, and beyond 60 feet they were all made upon the American system of construction known as the pin-and-link system. They were mostly made of Scotch steel. The bridges were exceedingly accurate in workmanship, the tools being specially made for the purpose. Long bars were worked for 40-feet links, and they were bored at both ends simultaneously correct to $\frac{1}{50}$ inch. Adjustments were provided for variations of temperature in the bar and in the machine. On his return he took an ordinary iron bridge, one of the best he had himself made, of 140-feet span, bow-string girders, and worked out the same in steel upon the American system to see whether with the same weights under similar conditions any saving could be effected, and he found that there was an actual saving in weight of 40 per cent. The cost of erection also would be enor-

mously reduced at the site and was altogether dispensed with at the works. Owing to the use of steel, the plates and bars were much longer than they could be if of iron. The cover-plates and riveting were much reduced. In fact there was very little riveting in American bridges, and scarcely any was executed upon the ground. The cost of erection, therefore, in an undeveloped country like that, was small as compared with what it would be under the English system. He did not think it was fair to compare the American system of railway construction with the English for England, but he thought it was incumbent to consider it carefully with reference to the colonies and countries to be developed. He entirely agreed with Mr. Gordon's statement that the essential differences between the English and American systems originated in the universal use of the bogie-truck in America. Every carriage and every car, and every engine in America was fitted with the bogie-truck. In England a bogie-truck could not be applied to goods wagons because the conditions were entirely different from those in America. In America a quantity of corn was put upon a car in the Western States and carried 2,000 miles to the sea-board. In England small parcels of goods were put into a wagon, which had to be shunted about at different junctions; and great dispatch was required, so that small wagons were necessary, which prohibited the use of the bogie-truck. The advantage of the bogie-truck was considerable, enabling the vehicles to go more smoothly round curves. He could not give a better instance than the Elevated Railroad of New York, which was worked more smartly than the Metropolitan Railway in London; yet the curves were 100-feet radius as compared with 660-feet on the Metropolitan. On the Canadian Pacific main line there were many curves of 8½ chains, or 573-feet radius, but the speed was maintained at 25 or 30 miles an hour with comfort and safety. There was no guard rail, as recommended by Mr. Mosse for curves under 10 chains. In a straight line also the bogie-truck had a great advantage on a cheaply-maintained road. He had himself travelled comfortably at 40 miles an hour over an unballasted road upon a car fitted with bogie-trucks, the road being in such a rough state that it would be alarming and probably very unsafe to travel over in an English carriage. Speaking generally, while it might be suitable enough in England to go on with roads expensively constructed and maintained, and worked with rolling-stock having a long rigid wheel-base with no flexibility and with an utter want of uniformity, it ought to be very seriously considered whether in the case of a new country like Burmah or China that system was in any way

Mr. Shelford.

Mr. Shelford. equal to the American. As to the financial part of the question, the Canadian Pacific, although it was a Government line, might be regarded as a financial possibility, because it was a cheap line, made upon the American system. It would have been a financial impossibility had it been a highly finished line upon the English system. Where money was no object it was better to make a highly-finished railway at first, but he thought that sound finance was of far more importance, and even cheaper in the end.

Sir Douglas Fox. Sir DOUGLAS FOX said that the discussion carried him back to the time when he first went to America in 1857. He remembered then being much struck with the very same contrast between English and American construction, which had been so plainly shown in the Papers under discussion. There could be no doubt that the main points of difference still remained the same. He did not agree with the statement in Mr. Gordon's Paper that the cause of the essential differences was the adoption of the bogie-truck in America. He believed thoroughly in the bogie-truck for certain purposes, and had used it extensively. It had been one of the means of introducing railways in an economical form into many parts of the world, where otherwise they could not have been constructed at any reasonable cost. But the great reason for divergence of design was that English engineers were dealing with a settled country, and American engineers with pioneer railroads leading to a great extent through thinly-inhabited countries, where they did not encounter many of the obstacles with which the English engineer had to contend. The great secret was set forth in the statement in Mr. Gordon's Paper—"Level-crossings are everywhere used, even in the largest cities, in the United States." That was a much more important reason than the use of the bogie-truck. In England engineers had to deal, especially of later years, with so many public highways, which must either be passed over or under without interfering with them, that an economical construction became a physical impossibility. Other points in England, which to a great extent did not arise in America, were the interference with residential property, the crossing of canals and of other railways, the Board of Trade requirements with reference to signals, and the cost of land, and all those considerations rendered it absolutely impossible to introduce such an economical system of railways as in a newly-settled country. But besides what had been done by English engineers in their own country, attention should be paid to what they had done in other parts of the world; and he ventured to say that the constructions carried out by English engineers in the colonies, and in India, would bear

comparison for economy with any work to be found in the United States. Great railways had been constructed in India which were thoroughly efficient, and in many respects much more substantial than the railroads in America, although many of them had been constructed at as low or even a lower mileage cost. He was glad to find, on the testimony of these Papers, that American engineers were coming to what he considered a sounder mind on several very important points. It was distinctly mentioned, for example, that re-construction, which was necessary if a railway was not properly and efficiently constructed and equipped in the first instance, was now found to be a most costly expedient. American engineers were also coming to the conclusion that a break of gauge was a mistake. The battle of gauges had been many times fought in the Institution of Civil Engineers as regarded the railways of Great Britain, and notably with reference to those of India. But if there was a country where uniformity of gauge had been specially departed from, it was the United States. When he first went there he found many different gauges in that country, all having their advocates, each maintaining that his particular gauge was the best. It appeared, however, that at present the opinion was gaining ground that the English standard gauge of 4 feet 8½ inches was the best that could be adopted. Another point, in which there was at one time a great difference between the practice of American and English engineers, was the weight of the rails. For many years the Americans never used a rail of greater weight than 56 lbs. per yard; but they were gradually finding out that, for the purpose of carrying a large traffic, that weight was not sufficient, and already, on some of the railroads, the weight of rail was almost equivalent to that on the London and North-Western Railway of England. The same thing was going on in India. On the narrow-gauge lines of that country, the weight of the rails was at first fixed by the Government at 40 lbs. to the yard—he believed very much against the advice of those interested in the railways. It now appeared from the experience of the traffic even there, where it was lighter than in the United States, that the weight of rail hitherto adopted was not economical in the long run, and the tendency was to increase the weight as much as the Government would allow. It was also found that, under the increasing requirements of rapid and heavy traffic, the cast-iron wheel was gradually disappearing, even from American railways. It was no doubt at one time a very good expedient for slow speeds, but the "survival of the fittest" was taking place, and the steel-tired wheel was gradually

Sir Douglas Fox.

Sir Douglas Fox. displacing the cast-iron wheel. Still further, the Americans were coming to the conclusion that it did not pay to haul an unnecessary amount of dead load. It might have been thought that such a conclusion would have been arrived at much earlier, but the very fact of the introduction of the bogie-truck, good as it was in many respects, had led to the practice to which he referred. They had been in the habit of constructing very long and heavy cars, and the result had been that the amount of dead weight, especially in the case of the Pulman car, had been excessive, as compared with what an English engineer would think a proper proportion. An illustration of one of the large cars with a bogie under the centre had been given, not merely providing a short rigid wheel-base, which was very important in itself, but also supports under the under-frame as close as possible. He agreed with the statement of Mr. Gordon, that as much engineering skill was required in laying out an economical railway as in designing an expensive one. It was, indeed, much easier to make an expensive railway than a cheap one under the same circumstances, and the object of every engineer ought to be, as far as possible, to adapt the work he had to design to the result to be obtained, at the least possible cost. If he did that he would be more likely to succeed than by aiming at a colossal work. Mr. Shelford had spoken of pin-connections, as a system largely adopted by American engineers. Many English engineers were as much in favour of pin-connection bridges, at any rate for abroad, as American engineers. He believed no system was more applicable for erections in countries where the transit was difficult, and where the local workmanship was not good. Bridges in India were, to a great extent, constructed in that manner, and the results obtained, as far as his experience had gone, had been most satisfactory. He did not, however, agree with the very deep girders adopted in the United States, except for timber-trusses. There was a great advantage in the American practice of introducing more sleepers under the rails than in England. That had arisen from two causes—first from the high cost of rails, and, secondly, from the fact that the sleepers were comparatively cheap. The aim should be to get as much bearing under the rails as possible. One important axiom had been laid down in the Papers, always to get as much room as possible for stations at starting. He agreed that it was almost impossible to make the station-yards too large to begin with. With regard to the comparison of locomotives, he had had the opportunity of using some of the best American locomotives beside some of the best English and Scotch locomotives, first on

railways during construction, and then on the same railways when completed and with their permanent-way in good order. His experience had been that, as long as the line was in a bad condition and in the hands of the contractor, no praise was thought too great for the American engine; but when it came into the hands of the Company, and economical working became the question, it was otherwise. That, he thought, arose from a very simple cause. The Americans had studied flexibility, and made their engines so flexible as positively to alarm Scotch and English locomotive makers. They did not understand such a thing as a tight fit, and they went upon the principle of making everything as loose as possible. The result was that on a roughly-laid permanent-way the American locomotive would keep on the road, while an English engine would soon find its way off. But the moment there was a good road to run upon, there was no comparison between the two engines in regard to the cost of repairs. Engine-builders ought not, therefore, to be tempted to forsake the good workmanship and the excellent fitting of the British engine, but at the same time they ought to try and give a little more flexibility, which was so valuable, and could be attained without any departure from sound principles of construction. Sir Douglas Fox.

Mr. J. W. Barry exhibited a diagram of a remarkably cheap railway, known as one of the contractors' overland lines, made by Mr. Firbank, in Sussex. The gradients were short and severe, namely, 1 in 7, 1 in 10, 1 in 13, 1 in 14, 1 in 20, and these were all worked by locomotives. The gradient of 1 in 7 was in a continuous length of 150 yards, and there was another length of 150 yards of 1 in 11. The sharpest curve had a radius of 250 feet. The line was in work two years, and carried about 60,000 tons without any difficulty. The length was 4½ miles, and there was 1 mile of sidings. A length of 4 miles was worked with locomotives, and ½ mile, which was too steep for a locomotive, being 1 in 4, was worked by wire ropes. The cost of construction, which was almost entirely upon the surface of the ground, was £7,200; and the equipment, including one locomotive, two stationary winding-engines, wire-ropes, sheds, and buildings for engines, was £2,875. The credit for the old materials was £3,449; so that the net cost was £6,626 for about 5½ miles of railway, or between £1,400 and £1,500 per mile. The gauge was 4 feet 8½ inches, and the weight of the rails 56 lbs. to the yard. The working expenses were about £1 18*s.* 3*d.* per mile per day. A traffic of 60,000 tons was conveyed over the line without accident; and double or treble the quantity might have been easily carried if it had been necessary. It would, of course, be seen that Mr. Barry.

Mr Barry. the cost per ton conveyed, which, including working expenses and interest, amounted to about 5*s*. per ton conveyed 4½ miles, was materially affected by the fact that the line was only in operation for two years, so that there was no opportunity of recouping the first cost of construction. The members of the Institution need not be afraid of steep gradients for cheap lines for temporary purposes; an enormous amount of traffic could be conducted with security and rapidity over those light temporary lines, in cases in which it would be impossible in the time at the disposal of the engineer to make anything better. He agreed that in a settled country like England cheap railways were not in the long run economical; but for light traffic, and where lines had to be constructed with great rapidity, engineers would do well to take a lesson from some of the cheap lines which contractors often laid for their own purposes, and which paid them uncommonly well. The indirect advantages also of those lines were very great, apart from the carriage of materials, in the facility given for getting backwards and forwards to superintend the works, and generally in the advancement of the enterprise.

Mr. Owen. Mr. G. WELLS OWEN observed that Mr. Gordon stated that it was evident "that railway construction must be carried out more economically in America than in England and in Europe generally;" and he proposed to mention the reasons for the difference; but, as it appeared to him, the Author had not mentioned many such reasons. True, he asserted that the essential difference between the American and the English practice originated in the use by the Americans of the bogie-truck. He did not think that that had much to do with it. No doubt the bogie admitted of sharper curves; but, except in the mountainous parts of America and Canada, sharp curves were not by any means a necessity. If, however, Mr. Gordon meant that by using the bogie-truck the weight was distributed more equally over the rails, and so permitted the use of a lighter permanent way, he could not agree with him, because it would be found that the weight per lineal foot on the rails was much the same with American as with English engines. The weight on the driving-wheels of the American engine (Fig. 4), with an 8-feet base, was 4·46 tons per lineal foot. In the case of a London and South-Western Railway engine, with a similar wheel-base for the driving-wheels, the weight was only 4·10 tons per lineal foot. Having recently made an examination of the western lines in Nova Scotia, with a view to the completion and consolidation of that system, he might be allowed to mention what he considered were some of the reasons

Mr. Owen.

why American railways were cheaper than English. He based his observations chiefly upon the result of his inspection of the Nova Scotia lines; but the same system of construction obtained to a great extent throughout Canada and the United States. The first reason which he would assign was the land, for which in America nothing had to be paid. The counties always gave the land to the railway company, even when they had to purchase it themselves from private owners. The next point was that of level-crossings. In the 200 miles of line which he inspected there was only one bridge carrying a road over the railway. It was often said in England that by the time the lodge was built, gates and signals had been put up, and the expense of men to attend to the level-crossing had been incurred, it was more extravagant in the end than the building of a bridge. But nothing of the kind was required in America. At a level-crossing there was simply a pole carrying a finger-post with the words, "Look out for the trains." There was no signal on the railway, beyond a piece of board nailed to a telegraph post, to show the driver when he was coming to a level-crossing. To prevent cattle from straying on the line there was an ingenious system of cattle-guards. Across the track a deep pit was dug, broad enough to prevent a bullock from jumping over. It had perpendicular sides and ends, and was lined with timber, and the permanent-way crossed it on longitudinal timbers. The fences, where there were any, were returned down to the edges of the pit, so that the cattle could not stray on the line. If they attempted to do so they fell into the pit, and lay under the rails until they were removed. Another reason for the cheapness was the fencing. Through the unsettled portions of the country there was no fencing at all. Sometimes snake-fencing was adopted; this was simply made by piling up the lesser logs of timber. Even where there was a permanent fence, it was what was called barb-wire fence, which was cheaper than anything of that kind in England, costing only 6*d.* a yard. The timber posts were 20 feet apart, and galvanized twisted wire was used. At certain distances apart four-pointed sharp barbs of wire were twisted into the wires, which prevented the cattle from rubbing against the fence and destroying it. Another reason for economy of construction was the small cost of timber. In Nova Scotia sleepers could be bought for 10*d.* each, and for trestle and timber bridges the cost was only 1*s.* per cubic foot of timber erected in position. In fact, so cheap was trestle bridging that it was the custom to use it instead of making embankments, and it was considered that it cost about half as much as bringing earth and tipping it. He had made

Mr. Owen. some estimates of the cost of trestle-work, and had found that it amounted to from £2 to £2 10*s*. per lineal foot, where the trestle-work was about 40 feet high. The cheapness of the timber, of course, also affected the cost of the stations and other buildings, which were constructed of that material. With reference to bridges, as Mr. Shelford had stated, the Canadians and Americans used very deep girders with pin-connections. When a bridge was to be put upon a line of railway, instead of the engineer designing it himself, the usual system was to apply to one of the bridge-building companies, who supplied, according to their own designs and standard patterns, so many lineal feet of bridging of certain spans. He exhibited some photo-lithographs of bridges erected upon a line which used to be called the Canada Atlantic, but which had been since absorbed by another company. One of those bridges had a span of 129 feet; depth of girder, 24 feet; width, 14 feet clear; the compression-members and floor-system were of steel, and the tension-members of wrought-iron. He believed that steel was now being used all through. These bridges were constructed to take a moving load of 3,000 lbs. per lineal foot, with an engine of 80,000 lbs. weight and 14-feet wheel-base. The weight of the engine was taken into account because of the cross-girders. The longitudinal-girders were designed so as to carry the moving load, but the cross-girders carried the greater weight of the engine upon the shorter wheel-base. It was a question whether that system of construction was cheaper than the English system. He had had occasion to get some tenders from the Dominion Bridge Company for about 1½ mile of bridging of various spans, and the estimate for the superstructure alone provided and erected was, for 100-feet spans, $45 per lineal foot; for 150-feet spans, $57; for 175-feet spans, $63; for 200-feet spans, $70. The moving load per lineal foot upon these bridges was taken for the 100-feet spans at 2,600 lbs., and for all the rest at 2,240 lbs., with an 80,000-lbs. engine on 14-feet wheel-base. Comparing these prices with those of English bridges, it would not be found that the Americans had much to boast of in regard to cheapness of bridge construction. Mr. Gordon had claimed that the American system of permanent-way gave not only a larger bearing-surface of the rails upon the timber, but also of the timber upon the ballast. He thought that Mr. Gordon was wrong in that statement, because he had found that the bearing of the rails upon the sleepers on American lines gave 1,322 square feet to the mile, whereas by the chair-system adopted in England there was nearly double that bearing. The American sleepers were 8 inches wide, while the English were usually

10 inches. Although rather more numerous in America, the general result was that the bearing of the sleepers upon the ballast was practically the same. Mr. Owen.

Mr. A. C. Pain noticed that, in the comparison between the cost of railways in England and abroad, nothing had been said as to one important item that had been forced upon English railway companies by the Board of Trade, namely, for interlocking and signalling. It was a large item, not only in first cost, but in working, as compared with a very small item on the main lines in any other part of the world. He thought that, as a rule, it was a great mistake to break the gauge. In America, India, and elsewhere on main trunk lines, much inconvenience had been experienced in practical working from that cause. But he believed it was also open to question whether a break of gauge was always undesirable. In England it might be assumed that nearly all the main lines had been made; but there were large outlying thinly-populated districts, where there was very little traffic, and the question was whether anything could be done to open them up. He had constructed and had had six years' experience in working a short length of narrow-gauge line; and it had led him to think that, if the main-line companies were to adopt a system of narrow gauges for their new branches, running engines of 9 or 10 tons (heavy enough for carrying traffic on lines earning from £6 to £8 a mile per week), there would be a great saving in first cost and in working expenses. If a main-line company had ten or twenty branches of that kind with a gauge of 3 feet, with engines and carriages interchangeable, there would be no more difficulty in working them than there would be in working branches of 4 feet 8½ inches gauge. The same system would be also applicable to railways abroad. If a country became so developed that the traffic largely increased, the narrow-gauge line might be taken up, and a heavier line laid; but in the larger number of cases the small capital and working expenses would be a great advantage, as compared with a heavy first cost and large working expenses. Mr. Pain.

Mr. G. B. Bruce, Vice-President, remarked on the statement in Mr. Gordon's Paper—"Mr. Dorsey claims that a railway can be constructed on the American system at from one-half to one-fourth the cost of the English system, and be in working order in from one-half to one-fourth the time." That was no reflection upon English engineers; but it was simply due to the circumstances in which they were placed. English engineers were working in an old country, where the traffic already existed; the Americans were working in a new country, where the work had to be conducted at Mr. Bruce.

Mr. Bruce. the cheapest possible price. In fact, the lines in America were something like that described by Mr. Barry, where the contractor laid a temporary line alongside of what was ultimately to be the permanent line, at a very small cost, by going not through the hills but over them, as in America. There lines, virtually of a temporary character, were laid down because there was no existing population to serve, and if the existing railway was weighted too heavily with capital in the first instance, it would be impossible to make the railways at all. In America it was absolutely essential that capital should be kept down; in England it was more expedient that the line should be made well at first, and that the working expenses should be kept under. The rapid construction of American railways was really due very much to the same thing. It was not that a man in America could turn a yard of earthwork more quickly than a man in England; but he turned fewer yards per mile as a rule. It was stated in Mr. Gordon's Paper that the average quantity was about 15,000 cubic yards per mile, an extremely small quantity. The district referred to by Mr. Shelford was in a rocky part of the railway, where the earthwork was said to be 44,000 cubic yards to the mile, but this was much above the average. The earthwork in England was necessarily heavier for a variety of reasons. In the first place reasonably easy gradients had to be made; and then there was a difference in the nature of the country itself. In America there were long stretches of prairie country which brought down the average cost immensely. One point mentioned in the Paper with regard to the total cost of capital was the buying up of bankrupt railways, Such concerns would be purchased at a very cheap rate, and that of course would to some extent help to bring down the average cost. He need not refer to the various points of difference to which attention had been already drawn. Fancy prices were paid for land in England, while land in America cost the companies nothing. Then there was an enormous difference between running up light bridges of timber (admirable for the purpose), and building stone bridges which were to last for all time. He believed that in the long run American railways would turn out to have cost as much as English railways, when the time had come for them to be put in the same good order, when stone platforms and stations were substituted for wooden ones, and when the roads were all ballasted. At present many of the American lines had no ballast at all, or very little, and that was often a heavy element in the cost. He did not wish to say anything disparaging to American engineers, because they had done the right thing; but in contrasting Eng-

lish railways costing £40,000 per mile with American railways costing £12,800 per mile, there was no common point of comparison. Reference had been made by Mr. Gordon to the important point of the relative weight of dead load of rolling-stock and the paying load. The American railway-truck was said to weigh 9 tons, and to carry a paying load of 27 tons, or three times the dead load. He did not think that anything like that had been done in England, where the carriage ordinarily weighed 5 tons, and carried 10 tons. It was worthy the attention of railway managers to ascertain whether it was not possible to diminish the dead weight. He greatly doubted whether it was possible, considering that American wagons travelled at 10 or 15 miles an hour, whereas many English wagons had sometimes, through the exigences of traffic, to travel at 30 or 40 miles an hour. Of course, the kind of traffic to be carried had much to do with the size of the wagon used. For large cargoes of grain travelling intact for very long distances, large wagons could be employed; but when trains had, as in England, to be split up, and half a truck-load sent to one place, and half a truck-load to another, it would be impossible to fill the enormous wagons used in America. The Americans seemed to rely a good deal upon the principle of taking enormous trains; and Mr. Gordon had spoken of trains with 3,000 tons of paying load, worked by three engines. Mr. Bruce should have thought that it would be better to divide such a train into three, and that there was not much gained by taking it in one. If the line and the rolling-stock were such that the train could be hauled by one engine, there might be something in it. Mr. Gordon had spoken strongly in favour of comparatively steep gradients. Mr. Bruce did not think that any general rule could be laid down on that point. Over the Rocky Mountains, a gradient of 1 in 25 might be used; but it would be foolish to have such a gradient if, by a small amount of earthwork, a better one could be obtained. It was all very well for a pioneer line to have a fancy gradient of 1 in 7; but that would not do for a permanent railway. Mr. Shelford had stated that the earthwork in America cost the same as in England, 1*s.* a yard—and he then stated that the cuttings were run to spoil, and banks made out of side cuttings. It had therefore to be doubled, so that the cost was really 2*s.* There was a good deal of food for consideration in what had been stated about the Canadian Pacific Railway; and any criticism passed upon it was not in any way meant to disparage the work that had been brought before the Institution. Mr. Bruce.

Mr. HUGH SUTHERLAND, M.P. of the Dominion of Canada, said Mr. Sutherland.

Mr. Sutherland. that he had been invited to listen to a discussion upon a subject on which of course all Canadians were interested, but he was not an engineer, though as a Canadian he had been more or less connected with the rapid strides that had been made in railway development in that country. At present there were in Canada 11,000 miles of railway actually in operation, which he thought would compare favourably with that of any other country. He believed that Canada had more miles of railway in proportion to the population than any other country. The cost of making railways in Canada had been materially reduced during the last few years. The mode of construction, the style of the superstructures, bridges, and the like, had been so materially changed, that a railway that now cost £5,000 or £6,000 a mile—would in his part of the country, Manitoba, be considered a high price—whereas heretofore it was twice that amount. In his comparisons with the Canadian and English railways he had been struck with the magnificence of the English railway stations, and the great amount of money expended upon them; and at the same time had wondered that the carriages should be so proportionately inadequate to the requirements and comforts of the travelling public. In Canada the order of things was reversed. Very rarely, and only at important points, were there any imposing structures in the way of stations. When a railway company incurred a heavy expenditure in the way of buildings it was called extravagant, but not so when it provided all the comforts that the travelling public required. He considered that the accommodation afforded in the Canadian cars was far in advance of that supplied on this side of the Atlantic. The public in America wanted comfort while travelling, and cared very little about railway stations. The style of bridges in Canada had been greatly altered, and they were now being constructed almost entirely of steel, very light but substantial. He had lived in Manitoba thirteen years, having followed up Colonel, now Lord, Wolseley in his expedition to the Red River at the time of the first Indian troubles. When he first went there he never thought he should live to see a railway built from the Atlantic to the Pacific all the way on British soil; like many others he had been amazed at the rapid construction of the Canadian Pacific Railway, of which the length open for traffic was now about 3,500 miles, including the lines that had been acquired. The territory to be opened in the north-west was, he believed, the largest and richest agricultural land unoccupied on the face of the globe. It was all British territory, and every Englishman should be interested in developing it. Railway construction there

was at present in its infancy. Branches of the Canadian Pacific and other lines were being promoted and pushed forward every day; the amount of capital invested in Canadian railways was about $600,000,000, and the number of miles opened was in the proportion of 1 mile for every five hundred inhabitants. If there were that proportion in England there would be about 50,000 or 60,000 miles of railway. It was not considered necessary in Canada to wait until the country was settled before a railway was constructed. It had been found that the best way of opening up an undeveloped country was to build a railway in advance of settlement. Where the conditions were favourable, the land good, and the climate satisfactory, as in Manitoba, settlement was sure to follow the construction of a railway. The Canadian Pacific was built rapidly and far in advance of the settlements, and already the railway was a paying concern, earning a considerable surplus over the expenditure. Last year he believed the earnings were upwards of $9,000,000, and the expenses about $7,000,000. He thought that showed a handsome return for a railway which was only in its infancy. All that Canada now required was emigration from England to fill up the territories of the north-west, and then not only the Canadian Pacific Railway, but three or four others, would be required to carry the produce of that immense country to Europe. Mr. Sutherland.

Mr. W. Martineau considered that the main points to be learned from the Papers, and the discussion, were the general principles by which engineers should be guided in the laying out and working of railways in undeveloped countries. Any general comparison between the American methods and those adopted in this country was, he thought, a little beside the question. Construction in a densely-populated country like England must necessarily involve considerations entirely different from those that obtained in a country where land was comparatively of little value, and where there were but few roads or private properties to be disturbed. The first point upon which he would like to insist was the absolute necessity of having an adequate, proper, and careful survey made before a line was laid out. In England, where there were ordnance maps and other facilities of the kind, that was of less importance; but in a country where railway promoters had to find their own routes, it was indispensable, as indeed was acknowledged by American engineers themselves. Every hundred pounds spent upon a good survey might be the means of saving at least £1,000 in the construction of the line. That was very often rendered difficult from the circumstances under which concessions were Mr. Martineau.

Mr. Martineau. obtained. Time was frequently of great importance, and works had to be begun to save the concession. After a line was made it was often found that if greater time had been bestowed on a careful study of it much money might have been saved. Again, in many countries steep gradients had been permitted, such as 1 in 50, or even 1 in 40. No doubt it was a temptation to engineers, where an opportunity was not allowed for proper study, to use gradients indiscriminately. Although a little time might sometimes be saved by adopting steep gradients and sharp curves, no one would contend that such a line could possibly be worked as economically as if more time had been bestowed in choosing a line with better gradients. Of course the conditions varied in different countries. Almost all the points touched upon in the Papers referred to construction on the North American continent where the lines passed through forests, where timber was abundant, and where its use in construction was therefore indispensable. But engineers were often called upon to lay out lines where those conditions did not exist. In some countries there was absolutely no timber, while in others, like Brazil, there were densely-timbered forests, and yet the timber to be obtained was not applicable, economically, to railway construction, being extremely heavy and difficult to work, and, although apparently so solid, often decaying with extraordinary rapidity. Engineers had therefore to inquire, in many cases, whether the use of iron, or steel especially, now that these materials were so much cheaper than they had been, might not be introduced with much more economy than timber even where timber was abundant. Whenever iron bridges were introduced the most economical plan was to endeavour to find out, as far as possible, one particular pattern that would suit the district and the circumstances, the various river crossings and the like, and to adhere to that pattern, so that the parts might be interchangeable, and no trouble arise from the designing of different bridges in different localities. He did not, of course, refer to the crossing of great, broad, and deep rivers, which was a subject hardly coming within the scope of economical railway construction. In some countries it was a great question whether iron sleepers might not be introduced much more economically than wooden ones. He had himself lately laid 6 miles of line in Brazil with iron sleepers. He began by sending two thousand as an experiment, and they were reported on so favourably by the superintendent after two years that the whole line was laid with sleepers of that kind. They were delivered in England at 3*s.* 9½*d.* each, and in Brazil for a little more than

4s., which was slightly in excess of what was paid for the timber sleepers of the country, which rapidly decayed. In such a case as that light iron sleepers were unquestionably more economical than wooden ones. He would only remind the members that there were in Great Britain, in spite of all that had been said about extravagant expenditure in railway construction, many instances of economical and sound construction which compared favourably with the works of any other country. Passengers were in the habit of going from Euston Station by the Scotch express, and finding themselves in a few hours in Glasgow or Edinburgh, without thinking that in doing so they passed over the greatest triumph of economical construction to be found in the country; he alluded particularly to the Lancaster and Carlisle Railway, and the Caledonian Railway, to those parts through Shap and over Beattock summit. Those lines were laid out nearly fifty years ago through some of the most hilly parts of the kingdom, and there was not one single tunnel on them. The whole contract expenditure, putting aside the expenditure for land and the expenditure forced upon English railways by roads and other circumstances, would compare favourably with the cheapest of American railways, especially when it was considered that the lines were made and were still worked for the great through traffic of the mail route between London, Edinburgh and Glasgow. The lines were laid out personally by one of the greatest masters of economical and sound construction in this or in any other country—Joseph Locke. Mr. Martineau.

Mr. B. Baker said that Mr. Martineau had raised several points of importance, but there was another point which he considered of even greater importance, namely, whether the railways of the future were to be made by English or by American engineers. In England railway work had been nearly completed, and there was very little worth mentioning remaining to be done; and if by superior skill in engineering, or economy in the mode of executing works, the Americans could build better and cheaper railways than Englishmen, they would be justly entitled to whatever work there was to be done in the future. But he did not think they could do so. It had been often stated that Americans built cheaper railways, but the work was not of the same kind. Consider for a moment how the cost of a railway was made up, and it would be seen that it was impossible. He had made an analysis of the cost of 43 miles of line which he had completed some time ago, in Ireland, in a poor part of the country, in the midst of a small population, and apparently under conditions which prevailed Mr. Baker.

Mr. Baker. in undeveloped places in America; yet the works of that line had cost £4,520 per mile, and it had been stated in the Papers that similar lines in America had been built for £3,000 per mile. He wished to point out that such lines could not have been similar in any respect. On the borders of Vermont he had to negotiate on the spot for the construction of a line through a poor country, and got the figures down to £3,000 per mile, but the works were entirely different. Pricing out the works on the American line at the Irish prices, he obtained the figures given in column B in the annexed Table, those going to make the £4,520 per mile already referred to being given in column A. By following the contour of the ground

Cost per Mile.	A.		B.
	£.		£.
Earthwork (quarter rock)	1,150	$\times \frac{2}{3} =$	766
Permanent-way and sidings . . .	1,790	$\times \frac{1}{2} =$	895
Fencing	260		
Bridges (35)	490	$\times \frac{1}{5} =$	316
Level-crossings (187)	270		
Stations (11)	560		
	£4,520		£1,977

more closely, the cost of the earthwork was only two-thirds of that in Ireland. By altering the permanent way and laying 56-lb. iron rails, instead of 70-lb. steel rails, taking the nearest timber to be found, and putting it in the road with all the sap, in a condition to last only two and a-half years, using only a nominal amount of ballast, and practically dispensing with bridges and station accommodation, a line of that sort might be built in Ireland under the same conditions for £1,977. For the Vermont line, as already stated, he had tenders from some contractors on the spot for £3,000; but although the £3,000 was lower than £4,520, it was 50 per cent. higher than the amount for which similar work could be done in Ireland. It might be asked, Why was it desirable to build a £3,000 line in one place, and not in another? It largely depended upon whether a company was spending its own money or that of somebody else. If it was spending its own money it would be economical to make the line for £4,520; but if it was spending the money of somebody else, and did not care whether the line was to earn a dividend or whether only to pay working expenses, it was a matter of indifference. In the case of Ireland the money was, as a rule, guaranteed by the counties, and if the line did not earn a dividend it had to be made up, and it had been found by long experience that, no matter how poor the country, or

how small the traffic, the true economy was to build lines, not like those mentioned in the Papers, which could be made for £3,000 per mile in America and £2,000 per mile in Ireland, but lines which could be afterwards worked at a low percentage. On the line to which he had referred the £4,520 per mile was sufficient to provide steel rails and creosoted sleepers which would last many years; bridges in every instance of stone or iron; the fence walls adjoining the bridges all of stone; the level crossings (one hundred and eighty-seven) had all iron gates, with solid limestone gate-posts, or if that could not be got they were built of masonry 3 feet square; the stations and level-crossing cottages were all of masonry, and the points, crossings, and signals were as perfect as on a first-class railway. Such a line could be worked at 60 per cent., while the other could only be worked at 90 per cent. of the receipts. The earnings, therefore, were in the one case 40, and in the other 10 per cent., so that with equal gross receipts the former would pay double the interest on twice the capital. That was the key to most of the differences that had been referred to. If the Americans would only give English engineers £3,000, or even £2,000 a mile for non-paying lines in Ireland, he believed they would build the works for that sum. But when Englishmen had to find money for themselves, knowing their own business as well as the Americans did, they had found by long experience that it was economical to build substantial and durable lines. Highly as he appreciated American skill and enterprise, he was not afraid of American competition, because almost every work in connection with railways depended upon the price of labour. The temperate climate of England must always give an advantage in that respect. Here, the average temperature of July was but 23°·5 higher than that of the coldest month. What the range must be in America was sufficiently indicated by the clause in American bridge specifications providing for 150° variation. The Americans were obliged to put an enormous duty on English rails, in order to prevent competition. It had often been said that they had a great advantage in sleepers, but he did not know that American engineers connected with important lines would now contend that they had an advantage over Englishmen even in regard to sleepers. On the Erie Railway the price was 3*s*. 3*d*. for oaken sleepers, which lasted seven years; for chestnut sleepers it was 2*s*. 6*d*., and they lasted five years; for hemlock sleepers, 1*s*. 9*d*., and they lasted three and a-half years. Dividing the first cost by life in years, it would be found that the average was about 6*d*. per annum per sleeper. Englishmen did much better than that, and he had no doubt that, Mr. Baker.

Mr. Baker. if the American railway managers had their choice, they would take English creosoted sleepers in preference to any they used themselves. In bridge-work for the colonies and foreign countries, he thought that English engineers would have to give their serious attention to American competition. A great deal of discussion had recently arisen in consequence of the open competition for a very important bridge in New South Wales. Sir John Fowler had recently been instructed to invite the bridge-makers of the world to submit designs and tenders for a work, the speciality of which was the very deep foundations—about 170 feet below the water-level. Nine designs and tenders were received from American, and nine from English firms; the lowest American tender was £265,650; the highest was £327,000; and the average of the nine was £290,120. The lowest English tender was £317,500, and the highest £580,000; the average being £440,150, or about 50 per cent. over the American average. Notwithstanding the disadvantages of protection in America, and other drawbacks, the contract was obtained by an American firm, that of a very worthy member of the Institution, Mr. T. C. Clarke. The conditions as to quality of steelwork, rolling-load, and working-stress, were identical in every respect. Such a result appeared very formidable at first sight, and of course a great deal had been made of it in the American papers; but having himself been behind the scenes, he did not draw the same inference from it as many Americans had done. One explanation, he thought, was that the Americans wanted the order, and were very keen to get it, sending over partners or representative engineers of eminence, not only to England, but to Australia, while most of the English bridge-builders were "riding for a fall," and rather afraid of getting the order; indeed he knew, as a matter of fact, that after they had made up their tenders on the most liberal prices their consciences would allow, many of them put on £50,000 or £60,000 for imaginary contingencies. One very well-known French firm, after sending in their first tender, asked to be allowed to reduce it by the amount of £170,000. He did not think that was a representative international competition for a bridge. He thought that the Americans were misled if they considered that the English offers were the best that could be made. He believed that very different tenders from English builders would have been obtained if the matter had been gone about in a more usual way. If Sir John Fowler and himself, or some other engineers, had prepared designs, and said that they were ready to stake their reputation upon them, lower tenders would have been received from the contractors than those

which they had sent with their own designs, because they rightly looked upon themselves rather as bridge-builders than as bridge-designers. He therefore did not attach much importance to the figures he had cited, as representing what competition would be when English engineers and builders were in earnest. There were advantages in the American type of construction for bridges in foreign countries which English engineers knew perfectly well —advantages belonging to the link-and-pin system, which, though sometimes spoken of as peculiar to America, had been in use in this country for a long period. Many of the very early English bridges were on the pin-and-link system,[1] which possessed, among other advantages, that of quick erection. Mr. T. C. Clarke several years ago had shown him some particulars with regard to a bridge of 160-feet span that he was erecting in Indiana. The men had the material all ready on trucks to run on to the temporary staging; they set to work on it at 8 o'clock in the morning; went to dinner at 1 o'clock (having to walk 1½ mile), and on their return saw that the bridge was well advanced, and said, "Why not finish it at once?" They accordingly buckled to, and finished the bridge by 5 o'clock. In another case, a viaduct with four spans of 150 feet was carried away by a sudden flood and ice. Although the level of the soffit of the bridge was 50 feet above low-water level, the rise in the Delaware River was so great that the ice lifted four of the spans off the piers, and sent them down the stream from 4 to 12 miles. The next day the iron for replacing that double-line railway bridge was ordered; in ten days the temporary wooden bridge was complete; in three weeks the first span was erected, and in thirty-two days from the date of the accident the bridge was finished. That was a smart piece of work, which, with present arrangements, perhaps, could not be done in England; but it certainly could be done, if the length of railways in this country were sufficient to justify an organization for carrying it out. Englishmen had performed some work of the kind on a small scale. When, for example, the Llandulais Viaduct, of the London and North-Western Railway, was washed away two or three years ago, a trestle bridge was put up in the first week; then Mr. Webb, at the Company's own works, rolled the steel and Mr. Baker.

[1] The links now being used in the erection of the Forth bridge were made sixty years ago. Howard's weldless links were introduced forty years ago, and were used on the Chepstow bridge, of 300-feet span, in 1849; on the Saltash bridge, of 455-feet span; and in the Usk, Windsor, and other bridges shortly after. The Newark Dyke bridge, of 240-feet span, had carried the heavy mineral and fast express traffic of the Great Northern Railway since 1852.—B.B.

Mr. Baker. manufactured the girders, buckle-plates, and everything complete for seven double-line spans, of 35 feet each, in a week; and the masonry piers were built and the girders erected in another week. The whole viaduct was rebuilt and the trains were running over it in less than a month. Again, the contractor for the Forth Bridge had to substitute a wrought-iron girder-bridge for a cast-iron arch-bridge, and he did it in six and a-half hours. He tumbled down the cast-iron bridge into the road, swung up the wrought-iron girders, and built up the masonry piers. It was not that English engineers could not do a smart piece of bridge construction if absolutely necessary, but simply that they were not called upon to do so, because, by the exercise of proper foresight in commencing the work at the proper time, there was no more necessity to scramble over the erection of a bridge than over the making of a locomotive or any other work. It had been said that English engineers laboured under a disadvantage as compared with American engineers, in consequence of the Board of Trade rules, but he could not understand the assertion. He had supplied the Board of Trade, from time to time, with American specifications, which it was found would meet all the requirements. The same thing had been said ten or eleven years ago when there was a discussion at the Institution about steel. Sir John Hawkshaw said he had applied to the Board of Trade for instructions as to what stress would be allowed on steel, and that he could not get an answer, so that he was unable to use steel in his works.[1] Sir Frederick Bramwell was also pretty severe at the time upon the Board of Trade in regard to the same point. Shortly afterwards rules for steel structures were framed by the Board, but he did not know that any bridge had been constructed under them. It was proved, therefore, to have been unfair to say that the Board of Trade prevented the introduction of steel in railway structures, when, the restrictions being removed, it had not been employed. He could not understand why engineers should use a material like bridge-iron, which would crack in bending to a very moderate angle, when they could have one 50 per cent. stronger, which would double up without cracking; but such was the case at present. The Board of Trade had nothing to do with it; and it was equally wrong to charge upon the Board other imaginary difficulties as arising under the present rules. He certainly had never had any additional expense imposed upon him by the Board of Trade officers, except for some oversight which they

[1] Minutes of Proceedings Inst. C.E. vol. xlii. p. 96.

had detected, and which he had been very grateful to them for detecting. Mr Baker.

Mr. EWING MATHESON thought the figures given by Mr. Baker with regard to the Australian bridge were a little misleading. The very high tender, which was lowered £170,000, was not an English tender at all, and the low average of the American prices was partly owing to some exceedingly low tenders, to which no attention was paid. The difficulties in the case were not those generally belonging to bridges, but had reference to the very hazardous and deep foundations, which were of a kind without precedent. The borings showed a necessity for going down 135 feet, and although the project was always considered feasible, it was thought to be hazardous and expensive. At a long distance from the place, and having but scanty information as to the foundations, no doubt the English bridge-builders did protect themselves to a greater extent than they would have done if the bridge had been in their own country. Mr. Matheson.

The general question had often arisen, why, with cheaper steel and iron, a bridge could not be built so cheaply in England as in America. The first reason for the extra cost in England was the want of uniformity; and the second was the higher standard demanded of quality and endurance, as compared with that in America. Any comparison that ignored those two points was fallacious. As to uniformity, nine-tenths of the bridges made in this country were for England, India, and the English colonies, and scarcely two were alike. Every time a bridge was constructed, the same process, as to the preparing of drawings and templates, had to be gone through. In America the railway engineer specified the results he wanted, and the bridge-builders competed to satisfy the requirements. The stock designs and patterns of the various firms were available, and all the bridge-building talent of the country was brought to bear upon the provision of what was best. The differences in quality were due to several causes. One of these was the difference between pins and rivets. No doubt the pin-system had certain advantages; it might allow a bridge to be put together in one day; but a bridge that could be put together in so short a time was not, to his mind, a satisfactory one. The bridges in America and in undeveloped countries had not to stand a heavy traffic, so that defects were not noticed; but, when the traffic increased, the bridges had to be replaced. It might be wise to put up cheap bridges at first, but when they had to do work at all approaching that of English bridges they soon became loose and untrustworthy. When he was first in America, in 1880, he heard of the famous

Mr. Matheson. bridge over the Ohio, at Louisville, with spans of 370 feet. He also saw in New York the Elevated Railroad, with some miles of spans of 60 feet, all having pin-connections. When he visited the Louisville bridge on a subsequent occasion, in 1885, there were watchmen employed day and night to screw up loose nuts, and to see that nothing had broken after the passage of a train before letting another train on. The enormous traffic on the Elevated Railroad had revealed the weakness of the pin-system, especially in the case of small pins, and riveted cover-plates had been substituted in the worst cases. The bridges were good enough for light traffic, and little of it, but were insufficient for constant traffic. Pins had often been employed in England. Sir Charles Fox used them in the manufacture of big bridges, and they were as good to-day as they were twenty years ago. They were not less than 4 inches in diameter, and the accuracy was such as to allow only $\frac{1}{100}$ inch play. The Americans allowed $\frac{1}{50}$ inch, and the diameter was brought down to 2 inches, and even $1\frac{1}{2}$ inch in subsidiary ties, and by hammering and rust they soon became loose. The whole plan of railway construction in America was different from that of English railways, and it was difficult to compare the two. He had travelled on main lines and important branches in America, where there were no stations—only a few sheds—no fencing, no ballast, no signals, and not a single over-bridge in 300 miles, every crossing being on the level, and when towns sprang up round the stations express trains could not be run. Every town had a municipal law that the trains should not run through at more than so many miles an hour. Signals, ballast, and fencing could be easily added, but not over-bridges, for all the approaches had then to be altered at great cost. If the Americans would content themselves with admitting that their system was the best as a temporary device in an undeveloped country, there would be nothing to say against it; but it was fallacious to compare the cost of American and English railways as if there were any common standard of comparison.

Mr. Marsh. Mr. T. E. M. Marsh referred to some cheaply-constructed lines of railway, or tramway, in Monmouthshire, that served all the large ironworks in that part of South Wales down to the year 1860. They were originally constructed under parliamentary powers obtained in 1792 and 1797. They did good service in developing the district, and in conveying the heavy traffic between the collieries and ironworks and the port of Newport. For a long period of years this was done by the freighters, some using locomotive engines and some horse-traction, there being no material alteration

in the original construction of the road. The work was done badly during the latter part of the time, but it was difficult to persuade the proprietors that the lines were not as good as was required. When, however, they became carriers on those lines, they altered their opinion. This was a necessary provision for the district, and to save their property from the attacks of rival railways. In 1845 powers were obtained by the Monmouthshire Canal Company for that purpose; and also to supply a railway between Newport and Pontypool, where their canal was unequal to the growing traffic. The original lines from the ironworks, situated at the outcrop of the minerals at the heads of the valleys at elevations varying from 800 to 1,100 feet, were laid out with a descending gradient the whole way, skirting the sides of the hills and coming down to join the canals. In 1792 unusual powers were obtained, which were useful in an undeveloped country, namely, to extend the lines, or to give others the power of extending lines, within 8 miles of any lines made in any direction. The canals were about 24 miles in length, and the tramways 44 miles. The entire cost was about £280,000. The tramways themselves in no case cost more than £2,000 a mile. £1,600 was a very general price. In changing to the new system the cost of improving the roads was about £1,000 a mile, wrought-iron plates of 75 lbs. being used instead of the old cast-iron, and wooden sleepers substituted for stone blocks. The traffic from the ironworks over the whole system was then carried by locomotives. In 1842 the proprietors of one of the largest ironworks furnished him with an elaborate statement showing the cost of the traffic. Six locomotives working from Tredegar to Newport—23 miles—conveyed the traffic in iron and coal down, and iron ore and goods up, at a cost, including all repairs of wagons and engines, of ½*d.* per ton per mile. One of the lines had since become the property of the London and North-Western Company, and was one of the most heavily worked in that system, and the others had become the property of the Great Western Railway Company. The old converted and the additional new lines of the Canal Company's system were about 58 miles, besides canals and old works. The capital in 1880 represented over a million, and 6½ per cent. was now guaranteed in perpetuity, the property having formerly always paid 10 per cent. on the old capital before its necessary enlargement for new works. Mr. Marsh.

Mr. J. Fforde said that reference had been made to the advantage of having standard gauges for enabling traffic to be interchanged. In Europe there was such an interchange, and it was possible to run from Calais or Antwerp to Brindisi, to Bucharest, Mr. Fforde.

Mr. Pforde. and Galatz; and no doubt shortly there would be direct communication with Constantinople, although there was no absolute uniformity of standard. He thought that a strict adherence to standards rather tended to prevent progress. He had recently travelled in some American railway cars in South America, and he did not think they would be regarded as comfortable or adapted to English traffic. They carried forty or fifty passengers, and there were only two exits—a door at each end. When stopping for refreshments thirty or forty persons would get out, and that occupied four or five minutes. Again, if a window at one end was open, it caused a draught through the whole car, which was excedingly uncomfortable. The Americans had been driven to use the Pullman cars, which were very expensive and heavy. He saw in South America an American locomotive, the framing of which ended at, and was attached to the fire-box, thus enabling the fire-box to extend outside the framing; the tank and foot-plate came on to the fire-box, and there was a two-wheeled bogie at the tail end. The pin on which the bogie swivelled was attached to a stud riveted to the back of the fire-box. If a locomotive of that kind got off the road, it would not be easy to put it together again. An intelligent engine-driver, who had driven both English and American locomotives, had said to him, "The American engines are very good and handy, and do their work well; but when they want extensive repairs you can do nothing with them—you must get a new one." As to the subject of pin-connections, he had had a great deal to do with pin-bridges, having been concerned in the erection of eight or ten of them twenty-five or thirty years ago, not one of which he believed was now in existence, all having been renewed. The relative bearing-surfaces of the pins and links were now better understood. He had lately had to erect some pin-bridges, and the difficulty of getting the pins in was surprising. He believed that a man at piecework would as soon erect a riveted bridge at the same price per ton as those with link-connections properly made, and unless they were properly made and fitted, he did not believe that they were trustworthy. Charing Cross bridge was not a fair example of the pin-system. It had no goods and no fast traffic over it, and the surfaces had been more accurately worked out than they had been in the bridges that had been renewed. The subject of laying out railways in undeveloped countries had not been much discussed; it was a very large one, embracing nearly the whole range of engineering, and it was impossible to deal with it in a discussion of that kind. Engineers were often tied down by regulations which restricted them in their designs.

It had been stated in one of the Papers that the advancement of the prosperity of a country was the chief object in view in the construction of railways. He knew of some railways which absolutely did not pay working expenses, and yet they were of much benefit. At certain times of the year they could not compete with the ordinary natural means of communication, yet they controlled the prices and kept down the exorbitant charges often made in the times of drought or flood. The difficulties encountered in laying out railways were often very great. The work was comparatively easy with the aid of ordnance and other trustworthy maps, but unreliable maps only added to the difficulties. He had laid out some railways in Portugal many years ago, and the best map that could be obtained showed a river running through a mountain range, and then passing out to the south of Cape St. Vincent. He accordingly laid out a line in the valley, thinking that he should easily get out of it, but he found that there was another mountain range, and that instead of the river running south it ran into the Atlantic Ocean to the west. A description had been given of the manner in which railways were laid out in America, where a cut-and-dried process was gone through, some men being employed in cutting down trees and others with the chain and the theodolite. It was different, however, in tropical countries, where a tree sometimes took a day to cut down. He remembered in one instance being stopped a fortnight by a hornets' nest; the men would not go near it, and they burned a fire round it until it was destroyed. Too great care could not be taken in going over the ground selected. It was generally the custom to decide upon a maximum gradient and a curve of minimum radius; and it often happened that when the maximum gradient was decided upon, it was put in on the slightest pretext. He could not impress upon engineers too strongly the necessity of carefully considering matters of that kind, because steep gradients were a constant drag upon a line, and always tended to increase the working expenses. In some cases, no doubt, steeper gradients than were often employed might be adopted. He might refer to the Serra do Mar incline of the São Paulo Railway,[1] laid out and constructed by Mr. Brunlees, Past-President Inst. C.E., in South America, with a gradient of 1 in 9·75. That line was now earning a large dividend. If it had been constructed on the usual principle, going round the mountains and extending four or five times the length, it was doubtful whether it would have been as profitable Mr. Fforde.

[1] Minutes of Proceedings Inst. C.E. vol. xxx. p. 29.

Mr Fforde. as it had turned out to be. Such gradients could be worked by means of ropes, or even by the Riggenbach system. The same argument applied to curves. Reference had been made to the Ceylon Railway with a gauge of 5 feet 6 inches, running round curves of 5-chains radius, which he thought was a novel feature in engineering, and had not attracted the attention it deserved.

Mr. Stileman. Mr. F. C. Stileman observed that Mr. Gordon had stated that corrections should be made before deducing a comparison between the cost of a mile of railway in America and in Great Britain. The figures given by him were accurate; but previous speakers had called attention to items of expenditure on English lines not required in America, and some further corrections should be made before finally deducing a comparison. He had further stated that while English lines had double tracks, the American mileage was chiefly single. That alone at once reduced the £42,000 to £26,800. Again, it was stated that the price of land in England was fanciful. Taking his own figures, the cost would be reduced £24,500 per mile. There were other items included in the general average making up the £42,000, such as steam-boats, harbours, docks, and canals. He did not know the exact amount spent on those works, but the cost of working them was £1,330,000 annually. Another serious item of cost on English lines was the rolling-stock; and he had been surprised to find that the amount of rolling-stock in America per mile was as followed:—

Class of Stock.	Number of Vehicles per mile.	
	England.	America.
Engines	0·78	0·20
Carriages . . .	2·41	0·16
Wagons	24·71	6·84
	27·90	7·20

In round numbers, the Americans had seven and a-quarter vehicles per mile as against twenty-eight in England. The reason for the much larger number of wagons in England was the short distances which they had to travel. In America each passenger travelled an average of 27 miles, and each ton of goods 110 miles; he did not know what the distance was in England, but probably it was only a mile or two. Another reason for the high average cost of Eng-

lish railways was this: it appeared from the Parliamentary returns that 62 miles in the immediate vicinity of London had cost upwards of thirty millions; that expenditure, taken at the general average cost per mile, would represent 1,000 miles instead of 62. He thought he might say of members of the profession, that, given any country with equal facilities, English engineers would be second to none in designing and laying out a line of railway, and there were plenty of contractors in England who would construct them as cheaply as those of any other nation, and in the same time. Mr. Stileman.

Mr. W. R. Galbraith said that one point to be considered was whether English engineers could take advantage of the information they received as to the construction of cheap railways in America. He had come to the conclusion that there were not likely to be many more cheap railways in England, and for a reason that had not been mentioned—the question of working. There was no room for any extended system of cheap independent railways in England. Short lines could not be worked with economy independently, and therefore the proprietors had to look to the large companies for assistance, and those companies would set their faces against any different classes of stock for light railways. He had made two of the first light railways in England some years ago—one to Sidmouth 8 miles in length, and another to Ilfracombe 15 miles in length, both of them being worked by the South-Western Railway Company. He found no economy, except in regard to the permanent-way. The South-Western Railway Company provided special engines for the lines, but when renewals became necessary it was found a great nuisance to have a different class of engines and rails, and the Company would have no more light railways, and resolved that all new railways must be capable of being worked by the ordinary rolling-stock. Accordingly, all the new lines now being constructed upon the South-Western system had the ordinary standard permanent-way. If that principle were carried out no great economy in construction could be hoped for, and therefore there was not much to learn from the American system, except perhaps that in many cases there had been extravagance in regard to stations. A costly permanent station was sometimes placed in a town where a much cheaper building would have done very well. When the South-Western Railway Company made the line to Exeter, and had to finish it in a hurry twenty-six years ago, a temporary wooden station was put up, which was standing at the present day; and when the station had to be enlarged, in consequence of increased traffic on the other side, a timber structure was erected which answered perfectly. He Mr. Galbraith.

Mr. Galbraith. believed it was wise economy to spend money on a good permanent-way, and that it paid the companies in the long run. American engineers, it appeared, had arrived at the same conclusion. The engines now coming into use on some of the older lines in America were as heavy as those in England, and there was one engine heavier than any that had been made in this country, and he thought that to run such an engine at a high speed over rails weighing only 60 or 70 lbs. a yard, fastened to sleepers without chairs, would be found to be a great mistake. If anything like the speed of the English express train were attained in America it would be found that there was nothing so good as the chair and sleeper and the double-headed rail. He supposed there was no permanent-way with a flange-rail better than that of the Metropolitan Railway, but the double-headed rail and sleeper was now being substituted, which really made the best road. The mileage working in America was $1 per mile, which appeared to be considerably in excess of the English working cost. He thought that English railways were worked at about 2*s*. 6*d*. per train-mile. The cost of the American passenger traffic was given at 1¼*d*. per mile; most of the English passengers were third-class, and were carried at a 1*d*. a mile. Many of the American railways seemed to be very little better than the line described by Mr. Barry, which was a temporary railway. Such lines would not be considered safe in England nor in her colonies. He remembered the late Mr. Edward Wilson giving evidence about a light railway in England. He was asked whether he had ridden over it, and he said he had, but he took care to walk back. When statements were made of wooden bridges put up in a day and of timber viaducts 300 feet high, perhaps some engineers present would admit the wisdom of this proceeding. Mr. Gordon had quoted (p. 70) "We can generally get through an accident to a passenger train, ditching the engine, baggage, and mail-cars, leaving the coaches on the rails with the occupants somewhat shaken up, but none the worse for their experience." If that was the general result of American railways they would not be suitable in England, where there was a great deal, perhaps too much, of paternal legislation. If Englishmen had erred in making too expensive railways, he thought that Americans had erred on the other side, especially with regard to the use of timber. Timber bridges had to be renewed every eight years. He disapproved of the inordinate use of trestle-work when some light embankment could be put down, which would be of a permanent character.

Mr. Burnett. Mr. R. H. Burnett remarked that he had some experience in the

working of railways of the character referred to in the Papers under discussion. As regarded locomotives, Mr. Gordon stated (p. 10) that "the sole essential difference" between English and American locomotives, "if it can be said still to exist, is the universal use of bogie-trucks." No doubt in the early history of American railways, when the lines were badly laid, and had sharper curves than were known in English practice, American-made locomotives were more flexible than English ones, and the use of the bogie was a marked feature of American practice. But that was now a thing of the past, and the bogie-engine, with a flexible wheel-base, was quite a common type of locomotive, as made and used in this and in other countries besides the United States. The question of bogie or no bogie was not by any means, in his opinion, "the sole essential difference," or even a main difference in the locomotives of the two countries; but it consisted in the general inferiority in the design, details, and materials, as well as in the finish, of American engines. From his experience of the working of American and of English locomotives on the New South Wales Government Railways, of which he had charge for several years as head of the Locomotive Department, American locomotives were much inferior, both in endurance and in economy in working, to English-made ones, notwithstanding that the American engines under his charge were constructed by one of the best-known makers in the United States, and might therefore be taken as representing the best American practice. Having had considerable practical experience, both in the making and in the working of locomotives, he had no hesitation in saying that wherein American practice differed from English practice, it was to the disadvantage of the efficiency and durability of the American engine. As showing that the opinion he had formed on the subject was shared by the present New South Wales railway authorities, and that English practice continued to answer best for the conditions of railway working in that colony at all events (a railway system which had much in common with those of other new and undeveloped countries), he might mention that in the specification recently issued by the New South Wales Government, under which tenders were invited from makers in this country and in America, the only features of American practice embodied therein were "rocking-shafts" for working the slide-valves, which experienced locomotive engineers knew to be the reverse of beneficial, and "extended smoke-boxes." The "bar-frame" was certainly named, but its introduction was incompatible with the width of the fire-box specified, namely 3 feet 6 inches inside. The details of con- Mr. Burnett.

Mr. Burnett. struction, as well as the materials used in English practice, were required to be adhered to by the specification. Even cast-iron wheel-centres, which the advocates of American locomotives had long claimed as being equal to wrought-iron ones used in English practice, while effecting a considerable saving in first cost, were excluded by the specification. Altogether the boasted superiority of American locomotives, either as regarded efficiency, durability, or economy in working, was without any foundation in fact. It was at one time, perhaps, a characteristic of American locomotives, that they were lighter on the rails than English engines, with less weight per axle, and that in this way lighter rails and fittings, bridges, &c., could be used, with a saving of first cost in construction; but if the weight mentioned by Mr. Gordon (p. 62) of the "American" engine was correct, that characteristic had disappeared. The total weight was given as 176,000 lbs., or 78 tons. Exclusive of the tender, it was 112,000 lbs., or 50 tons, with 40,000 lbs., or 18 tons, on each pair of driving-wheels. That was more, he thought, than was known in any other country. No wonder that American engineers were beginning to find it necessary to use heavier rails.

Next, as regarded the use of bogie-trucks in place of four-wheeled vehicles. Mr. Gordon's remark (p. 55) that "the essential differences between American and English practice originate in the universal use by the former of the bogie-truck . . . as compared with the general use of longer wheel-base and more rigid connections by the latter," had already been referred to by previous speakers, and he mentioned it now simply to endorse, from his own experience, the views that had been expressed. Doubtless the use of the bogie-truck constituted an important difference in the practice of the two countries, as affecting the alignment of the road. But the dead-weight of trucks constructed on the bogie principle would be found to exceed that of ordinary four-wheeled wagons, if of the same strength, unless they were made long enough to carry not less than from 20 to 22 tons each, as against the 9 or 10 tons carried on a four-wheeled truck weighing 4½ or 5 tons used in this country; and, as had been pointed out by previous speakers, such large trucks as those were not suitable for general traffic. The question of dead-weight and paying-load was in a nutshell; it was simply a question of speed. The New South Wales traffic authorities, having been somewhat impressed by reports of American performance in that direction, proposed that the maximum loads for the goods wagons should be increased, to raise the proportion of paying-load to dead-weight, which was

necessarily comparatively low on lines with steep inclines, such as those on the New South Wales railways. He increased the maximum from 7 tons to 8 tons; but, of course, there was a limit, having due regard to the strength of the axles and springs, and he did not think it judicious to go further. No saving in dead-weight had been effected, nor ever would be, *per se*, by the adoption of the bogie-truck form of construction, because, strength for strength, it was heavier than the four-wheeled system. Take, for example, the weight of the "Pullman" bogie-car in comparison with that of four-wheeled or six-wheeled carriages, with equal space and accommodation for passengers as used in this country. In the endeavour to raise the average of the paying-load to the dead-weight, the American railway authorities marked on the trucks a much higher maximum load than would be admissible with the higher speeds at which goods trains were run in other countries, having due regard to wear and tear and safety, and no doubt their trucks were frequently loaded up to that higher standard, with the result that they must run more slowly in proportion. Of course it was an easy matter to mark a high maximum load on a truck, and to load it occasionally up to that high standard, and then to boast of reducing the proportion of dead-weight. For example, it would be easy to mark, say, 15 tons on an ordinary English four-wheeled wagon in place of 10 tons, and to load it accordingly, if the nature of the material admitted of it. But with what result? It would soon be knocked to pieces, and what was saved in cost of haulage would be more than absorbed by repairs, and loss by break-downs and accidents. All he need add was that the bogie-trucks sent over to New South Wales from the United States, as examples of the best practice in that country, were vastly inferior in strength to the four-wheeled stock in use in the colony, and were marked for loads which could not be considered safe, except at very slow speeds, or for use on level lines; because a succession of very steep rising and falling gradients, such as were peculiar to the New South Wales railways, and were common to railways in most undeveloped countries, were very trying to the under-frames of the rolling-stock as well as to the wheels and axles, on the application of the brakes or sprags, and necessitated greater strength than usual. In New South Wales, notwithstanding every disposition from indirect causes to introduce American rolling-stock, very few trucks on the bogie-system had been introduced. Although the number of goods vehicles on the railways at the end of 1884 (the last returns) amounted to 8,500, the number of bogie- Mr. Burnett.

Mr. Burnett. trucks for goods traffic were extremely few. That fact alone spoke volumes against the utility for general purposes of the American bogie-truck. He would next refer to the New South Wales railways, as an example of cheap, and at the same time substantial, railway construction, and therefore very apposite to the subject of the Papers under discussion. While not wishing to disparage the ability and ingenuity which American engineers had shown in constructing cheap lines in their own country, he thought it was only right to put on record an instance within his own experience, showing that English engineers had not been behindhand in producing equally cheap and serviceable railways in countries under conditions similar to those in the United States. As his testimony was that of an observer, and not an actor in the work, it was quite impartial. The Engineer-in-Chief, to whom the credit was due, was Mr. John Whitton, M. Inst. C.E., an Englishman who had been Engineer to the Government of New South Wales for many years. From personal observation Mr. Burnett could speak with confidence as to their substantiality, and suitability for their purpose. From knowledge acquired on the spot, and from official sources, he could speak as to their cost. He had prepared the annexed Table, showing, in a convenient form for reference, the lengths of the various sections opened for traffic from time to time, with the width of cuttings and formation, the ruling gradients, and curves; the character of the permanent-way, and the cost of each section. He would now give, as briefly as possible, a summary of them. These railways consisted of three main lines, with several branches. The main lines ran from the sea-coast to the interior, one line south-west, one due west, and the other north-west, and all had to cross the main mountain range, which extended from north to south at no great distance from the coast. They were laid to the 4 feet 8½ inches gauge, and were chiefly single lines. At the end of 1884 there were 1,618 miles in operation, on which had been spent £17,000,000 for construction, and £3,000,000 more for rolling-stock, machinery and workshops, &c. That gave an average of somewhat more than £10,500 per mile for construction, and of £1,850 for rolling-stock, &c. It would be seen by the Table that the greater part of these lines had been constructed over very rough country, hundreds of miles having constantly recurring gradients of 1 in 40 and 1 in 50, with many miles of 1 in 33, and even 1 in 30, rising in some cases to heights of over 3,500 feet in crossing the mountain range to reach the table-lands of the interior. This average of £10,500 per mile compared favourably with the average cost per mile named by

Mr. Gordon (p. 55), namely, £10,000, as the cost of railways in the United States, when it was taken into account that the rates paid for wages and materials in New South Wales had been such as to add about 66 per cent. to the price of similar work in this country, and probably at least 33 per cent. to the prices in the United States. Moreover, the average of £10,500 per mile in New South Wales included all extra money spent up to date in widening the lines and in increasing the accommodation required to meet the increased traffic over the older portions of the lines, as well as the cost of the land actually paid for, which amounted in the total to a little over £500,000, or about £300 per mile. The interest paid by the net profits on the lines in operation for the year 1884 was 4·2 per cent. He need hardly say that the cost of construction had varied considerably on different sections, according to the character of the country. On the Great Western main line the highest cost had been reached, although on some portions it was low. As it was characteristic of the other main lines, it might be interesting to give a few particulars. Taking the line at the commencement of its ascent over the mountain range, one length of 111 miles—from Penrith on the east side of the range to Bathurst on the west side—by which the range was crossed at a height of 3,658 feet, cost close upon £17,000 per mile on the average; although considerable portions cost as much as £20,000 per mile, or more, owing to the broken and precipitous nature of the country, which necessitated heavy works, notwithstanding that frequent gradients of 1 in 33 increasing at some places to 1 in 30 of an aggregate length of 17 miles, with curves of 8 chains (528-feet radius) were adopted. In a length of 30 miles an ascent of 3,270 feet had been made, or an average gradient for that distance of 1 in 48. An ascent of 527 feet was made in a length of 3 miles, or 1 in 30, and a descent on the other side of 497 feet in a length of 4 miles, or 1 in 42, by zigzags, over the middle section of which the trains were pushed backwards by the engine. As showing the circuitous course which the line had to be taken to avoid heavy works as much as possible, the termini of this length, Penrith and Bathurst, were 70 miles apart, while the actual distance by rail was 111 miles. The rails used on the mountain section were 75 lbs. per yard, carried on chairs weighing 25 lbs., fixed to hard-wood sleepers 9 feet long by 10 inches wide by 5 inches thick, placed 3 feet apart from centre to centre, well ballasted to a depth of 8 inches under the sleepers, the formation width being 18 feet, and the embankment slopes 1½ to 1. Beyond the mountain section the rails were Mr. Burnett.

Mr. Burnett.

COST of the NEW SOUTH WALES GOVERNMENT RAILWAYS

	Name of Section.	Length.	Ruling Gradient.	Minimum Curves.	Level of Lowest and Highest Points.
		Miles.		Chains.	Feet.
Main lines between sea-coast and base of mountain range [1]	Suburban (Sydney to Granville junction).	13	1 in 100.	easy.	16 / 100
	Great Western (Granville to Penrith) .	21	1 in 66	30	20 / 183
	Great Southern (Granville to Picton) . .	40	1 in 66	30	20 / 549
	Great Northern (Newcastle to Singleton).	49	1 in 63	30	2 / 300
Great Western main line	Penrith to Bathurst [2] .	111	1 in 30 and 1 in 33 for 17 miles, remainder 1 in 40	8	88 / 3,658
	Bathurst to Dubbo .	133	1 in 40	12	2,153 / 3,150
	Dubbo to Byerock. .	177	Easy gradients &curves		..
Great Southern main line	Picton to Goulburn [2] .	81	1 in 30 and 1 in 33 for 5 miles, remainder 1 in 40	20	549 / 2,357
	Goulburn to Albury .	252	1 in 40	20	531 / 2,392
	Albury to junction with Victorian railways .	1	Easy gradients &curves		531
	Carried forward.	878			

[1] These main lines, having been made in the periods of an unsettled labour market, and without the colony. See other portions of the main lines.

Mr. Burnett.

a December 31, 1884. 4 feet 8½ inches gauge.

Particulars as to Cuttings, Embankments, Permanent-way, &c.		Cost of Way and Works. Total.	Cost of Way and Works. Per Mile.	Remarks.
		£.	£.	
Formation width 30 ft., with slopes in cuttings of 1 in 1 in ordinary earthwork. Through rock the sides are perpendicular, or slope of ⅛ or ¼ to 1. Embankments 30 ft. wide at top, with slopes 1½ to 1. Ballast 12 in. deep under sleepers	Rails double-headed, 75 lbs. per yd., fished, and carried in chairs 25 lbs. each, fixed to iron-bark, blue-gum or box-wood sleepers, 9 ft. × 10 in. × 5 in., placed 3 ft. from centre to centre .	749,265	57,636	Double line, and includes 16 miles of sidings and terminal station, &c.
Formation width 18 ft., with slopes same as above. Ballast 12 in. deep under sleepers	Do. do.	310,788	14,800	Single line.
Formation width for 9 miles 30 ft., remainder 18 ft., with slopes same as above. Ballast 12 in. deep under sleepers	Do. do.	669,620	16,740	Do., but 9 miles formed for double line of rails.
Formation width for 17 miles 30 ft., remainder 18 ft., with slopes same as above. Ballast 12 in. deep under sleepers	Do. do.	779,999	15,918	Single line, but 17 miles formed for double line of rails.
Formation width 18 ft., with slopes same as above. Ballast 6 in. deep at middle and 8 in. at sides, under sleepers, and 10 ft. 3 in. wide at top	Do. do.	1,878,747	16,926	Single line. Very heavy works. Total excavation, principally in rock, was 5½ million cub. yds.
Formation width 15 ft., with slopes same as above. Ballast 6 in. deep at middle and 8 in. at sides, under sleepers, and 8 ft. 7 in. wide at top	Rails single-headed, 70 lbs. per yd. (Vignoles), fished and fixed direct to the sleepers, 8 ft. × 9 in. × 4½ in., placed 2 ft. 8 in. from cen. to cen.	1,007,461	7,575	Single line.
Do. do. do.	Do. do.	1,034,509	5,845	Do.
Formation width 18 ft., with slopes same as above. Ballast 6 in. deep at middle and 8 in. at sides, under sleepers, and 10 ft. 3 in. wide at top	The heavier permanent-way, as above .	1,026,548	12,673	Do.
Formation width 15 ft., with slopes same as above. Ballast 6 in. deep at middle and 8 in. at sides, under sleepers, and 8 ft. 7 in. wide at top	The lighter permanent-way, as above, but steel rails . .	2,150,481	8,534	Do.
Do. do. do.	Do. do.	100,203	100,203	Crosses the river Murray; includes an exchange station with the Victorian system.
Carried forward		9,707,621		

ordinary facilities for such work, cannot be taken as any criterion of the cost of railway construction in the

a Ascending mountain range.

Mr. Burnett.

Cost of the New South Wales Government Railways

	Name of Section.	Length.	Ruling Gradient.	Minimum Curves.	Level of Lowest and Highest Point.
		Miles.		Chains.	Feet.
Brought forward		878			
Great Northern main line	Singleton to Murrurundi[1]	71	1 in 50	30 1 curve 20	135 1,550
	Murrurundi to Tamworth	62	1 in 40	12	1,195 2,113
	Tamworth to Glen Innes[1]	141	1 in 30	8	1,195 3,700
Inland branches to main lines	Wallerewang to Mudgee	85	..	..	..
	Junee to Jerilderie	232	Easy gradients & curves		..
	Werris Creek to Narrabri	97			
Branches in vicinity of Sydney and Newcastle	Darling Harbour (in suburbs of Sydney)	1	Falls 60 feet with easy curves		..
	Bullock Island (in suburbs of Newcastle)	1½	1 in 200	12	..
Sundry short branches		49½	..	..	..
Total of lines in operation		1,618			
Rolling stock					
Machinery and workshops, &c.					

[1] Ascending mountain range.

Mr. Burnett

...o December 31, 1884—*continued*. 4 feet 8½ inches gauge.

Particulars as to Cuttings, Embankments, Permanent-way, &c.		Cost of Way and Works. Total.	Per Mile.	Remarks.
		£.	£.	
Brought forward		9,707,621	..	
Formation width 18 ft., with slopes same as above. Ballast 6 in. deep at middle and 8 in. at sides, under sleepers, and 10 ft. 3 in. wide at top	The heavier permanent-way, as above	724,264	10,200	Single line.
Formation width 15 ft., with slopes same as above. Ballast 6 in. deep at middle and 8 in. at sides, under sleepers, and 8 ft. 7 in. wide at top	The lighter permanent-way, as above, but steel rails	414,930	6,690	Do.
Do. do. do.	Do. do.	1,633,842	11,587	Do.
Formation width 15 ft., with slopes as above. Ballast 6 in. deep at middle and 8 in. at sides, under sleepers, and 8 ft. 7 in. wide at top	The lighter permanent-way, as above, but steel rails	932,317	10,968	Do.
Do. do. do.	Do. do.	1,320,738	5,908	Do.
Do. do. do.	Do. do.	552,013	5,691	Do.
Formation width 30 ft. Ballast 12 in. deep	The heavier permanent-way, as above	135,238	135,238[2]	Double line.
Do. do. do.	Do. do. but steel rails	47,206	31,471[2]	Do., and includes 4 miles of sidings.
.. ..	.. ..	617,221	12,469	Single line.
Additional spent up to date (end of 1884) in widening some portions of the lines and in increasing the accommodation on the older portions to meet the growth of the traffic		1,004,602	..	
		17,089,992[3]	10,562	
. . . . 2,533,631 / 464,547		2,998,178	1,853	
		20,088,170	..	

[2] The high cost is chiefly for land and compensation for disturbance.
[3] Includes cost of land, amounting to £539,000, chiefly incurred in the Sydney and Newcastle districts.

Mr. Burnett. 70 lbs. per yard, of the Vignoles pattern, fixed direct to sleepers 8 feet long by 9 inches broad by 4½ inches thick, placed 2 feet 8 inches apart from centre to centre, the formation being reduced to 15 feet. The cost of the next section to the west, 133 miles long, over easier country, but with railway gradients of 1 in 40, with the lighter permanent-way, was £7,500 per mile. The length beyond that, of 177 miles, extending towards the western boundary of the colony over still easier country, and with the lighter permanent-way, cost only £5,800 per mile. Various branch lines, amounting to about 330 miles, and laid with the 70-lb. steel rail, likewise cost about £5,800 per mile. It was interesting to learn, on Mr. Gordon's authority, that the 4 feet 8½ inches gauge, which was adopted in New South Wales, the oldest of the Australian colonies, but which, unfortunately, was not followed by any of the other colonies (Victoria to the south having adopted the 5 feet 3 inches, and Queensland to the north, as well as most of the other colonies, having adopted the 3 feet 6 inches gauge), was likely to become by the end of the year, on the principle of the survival of the fittest, the universal gauge of the United States, as it had already become so in this country.

Mr. Crampton. Mr. T. R. Crampton said the question appeared to be what should be done in future to make railways cheaper. The roads could not be too strong if the rates of speed were great, but it was a question whether the rates which the existing type of locomotive could deal with economically had not been exceeded. His own impression was that the whole system of locomotives was faulty. It was a bold thing to say, but he was prepared to repeat what he had said in 1849, when before his seniors he had laid down certain principles with reference to the construction of locomotives. Indeed, he had not a word to change in the Paper which he then submitted.[1] The engines then ordinarily constructed, and which, unfortunately, were being still constructed, were based upon wrong principles. He had shown that in the best engines of the time there was a lifting action on the front wheels of 25 cwt., while according to his system it was only 5 cwt. In 1848 he was selected to design the first locomotives for express trains in France, and they had been running for thirty-five years, without altering the dimensions of a pin, or of a bearing. They had been renewed over and over again, and had run 22,000,000 miles at a cost of 1½*d.* per train-mile, and were still at work. Twenty-seven engines had run for seven and a-half years 34,000 miles a year, at a

[1] Minutes of Proceedings Inst. C.E. vol. viii. p. 233.

cost of $\frac{5}{8}$ of a penny per mile without renewals. One reason of this was that in his system there was not a pin nor bearing beyond reach, and which could not be touched and lubricated, whether the engine was running 50 or 60 miles an hour, or standing still. Other reasons were—the employment of large wearing surfaces, low centre of gravity, no overhanging weights, the greatest weights being on the extreme wheels. Locomotive engineers had apparently lost sight of the vertical action to which he had referred, as the 25 cwt. of lifting action in some of the present engines amounted to 4 tons or more; besides this, the alternative strains from the pistons to the axle-box guides and frames were as much, in many cases, as 16 or 17 tons, which latter could be entirely obviated. Surely such effects could not be conducive to the good maintenance of the permanent-way, or to economy in the wear and tear of the engines? He thought it would be interesting to investigate what had been done by the outside cylinders and machinery on the Continent during the last thirty-five years. Bodmer in 1841–2 had devised a type of engine which Mr. Crampton thought would have ultimately to be adopted, at least in principle. It was absolutely steady; there was not a cross-strain on the frame in any way, and there was no tendency to oscillation from the machine itself, all the moving parts being counter-balanced. For two years he had tried to bring that system into use; but, unfortunately, it was too complicated, though now it could be practically adopted. Twenty years ago, Mr. Haswell had tried a method of that kind on one engine, but it was carried no farther. Now that heavy engines were running with 18 tons upon a pair of wheels, and subject to such strains as previously mentioned, how could it be expected that the permanent-way or the engines should be long-lived? More attention should be devoted to the principles of locomotive construction, to give light and cheap railways the best chance of succeeding. Mr. Crampton.

Mr. W. Shelford, in replying for Mr. Granville C. Cuningham, regretted that the discussion had drifted rather into a defence of the English system of railway construction, the excellence of which as applied to England had not been challenged, and had dealt but little with the question raised by the Papers—"the construction and working of economical railways." No one who had seen the Rocky Mountains, and Selkirk summit section of the Canadian Pacific Railway, would compare it with a contractor's line, or would doubt that it was equal in all essential points to colonial railways, and even to the less important lines in England a few Mr. Shelford.

Mr. Shelford. years ago. It was, indeed, superior in respect of grades and curves to some of the colonial lines described by Mr. Mosse, and the permanent-way was at least equal to that now in use on the continent of Europe; nor was it inferior to that employed in England on the lighter lines until the requirements of the larger companies, as to uniformity of pattern, brought about the general adoption of the double-headed rail secured by chairs. The bridge over the Columbia River was an excellent work.[1] In American timber bridges any piece could be replaced, and one system was adopted, so that the castings were all made to standard patterns, and were easily obtained for speedy construction, or if renewals were required. The "pin-and-link" bridges had been greatly improved in the last few years, and the use of steel contributed to their success. It was possible that they were not adapted to the high speeds and frequent trains run in England, but in undeveloped countries those conditions did not exist, and they possessed great advantages in lightness and in economy in cost and time of erection. The Americans could construct an ordinary girder-bridge cheaper and better than the English at the present time, however unpalatable that truth might be, because they had a system for which their works and machinery were laid out and adapted, which secured great accuracy. Also few templates were required, and no erection at the works was necessary, which meant considerable economy. If this were compared with the absence of system in England, the great variety in detail of designs, the numerous templates, costly erection at the works, and the absence of the best machinery for "pin-and-link" manufacture, the reason why Americans had beaten the English in Canada, and even in Australia, would be easily understood. He considered that in a new and extensive country the following points were essential, viz.:—1. A road which need not be maintained with accuracy and at heavy cost; 2. a flexible rolling-stock to work on such a road; 3. dispensing with station-accommodation as far as possible, and carrying it on the train. He thought that the last point, at all events, was best met by the American train of cars with a passage through it, because all parts were accessible, and very short station-platforms were sufficient; but he admitted that the dead-weight per passenger in their cars was much greater than in the English carriages. The objection made to these cars, that they could not be quickly emptied, was not found to apply in New York, where, on the Elevated Railroad, carrying a large number of passengers,

[1] Minutes of Proceedings Inst. C.E. vol. lxxxii. p. 345.

the trains only stopped at the stations for fifteen seconds. He had no desire to undervalue the English system of railway construction, in which for many years he had taken part, but he felt it incumbent upon him to point out that, in his opinion, that system as applied to newly-developed countries might be much improved by a study of recent American practice. Mr. Shelford.

Correspondence.

Mr. W. Atkinson remarked that the economical construction and working of railways in new countries had been brought to the notice of the English people with peculiar force, both by the great reduction thereby effected in the cost of food supplies, and the consequent diminution in the value of land. There were at least three important elements to be noticed—the construction, the working, and the subventions in their various forms. Taking this last as a starting point, and referring to Mr. Gordon's remark that "most of the land belonging to the American companies cost them nothing," it might be added that many of them had, in addition to the land for their road-track, enormous land grants. Taking a minor instance, the Chicago, Burlington and Quincey Railroad Company had grants of 2,723,000 acres, realising £3,500,000. Five per cent. on this, or £175,000 a year, was, for all time, a bounty on the traffic of the line. Passing to Canada, and the Intercolonial Railway built by the Dominion Government at a cost of say £5,000,000, this at 4 per cent. was a bounty of £200,000 a year on the traffic; for after a lapse of sixteen years the line just earned its working expenses. The Canadian Pacific had its enormous land grants. In France, Spain and Italy the lines received State aid. In India guarantees had acted as bounties on exports; and in Australia and in New Zealand the lines had been built or assisted by the Government; while in the Argentine Republic and in Brazil, large guarantees had been given by the Government, amounting in the case of the Bahia and San Francisco Railway to an annual bounty of £120,000; for, since the opening of the line more than twenty years ago, it had never earned its working expenses. Thus most of the Governments of the world had given State aid to the railways, resulting in a bounty on the exportation of their own produce, and by this subtle means had abstracted the value of the land in this country and transferred it to their own. As an illustration of the cost of construction on the American continent, Mr. Gordon had taken the Chicago, Milwaukee Mr. Atkinson.

Mr. Atkinson. and St. Paul Railway, of which 3,400 miles had cost £7,600, and 1,600 miles about £3,500 a mile; and various speakers seemed to assume that the conditions of construction compatible with the latter expenditure were generally adopted by the people of the United States. This was often not the case, as they knew well that where money was available it was better to construct a thoroughly good line at the beginning. As an illustration, a line of 360 miles was in course of construction from Savanna by the east bank of the Mississippi to St. Paul, being in the country of, and in opposition to, the Chicago, Milwaukee and St. Paul line. This line was to cost with equipment £7,500 a mile in cash, and, it was believed, would be thoroughly well built. There were many crossings of large rivers on the route. The original estimate for the Intercolonial Railway was £9,200 a mile, without equipment; and the portion through the province of Nova Scotia he estimated, with equipment, £10,600 a mile, no timber bridges or viaducts being contemplated. These prices indicated not only thoroughly good materials, but that the countries were difficult for railway construction. In India, in the Nizam's territory, a line of 87 miles had just been completed and equipped at a cost, excluding land, of under £6,000 a mile, the rails being 66½ lbs. per yard of steel, and the sleepers steel also. The gauge was 5 feet 6 inches. This sum included fencing, though that had not been put up. This line had been promoted by the Indian Government, and everything connected with it had been examined and approved by its consulting engineer. From these two examples it would be seen that under circumstances of considerable disadvantage good lines of 4 feet 8½ inches gauge, capable of carrying heavy traffic, could be built and equipped at the present time at from £6,000 to £7,500 a mile, and these figures might be taken as representing economical construction in such countries. Mr. Gordon had given the charge for carrying 1 ton a mile at 0·695*d.*, and a passenger 1 mile at 1·26*d.* on the Chicago, Milwaukee and St. Paul line. The question of operating expenses deserved a much more extended treatment, as it was so important a factor in the result of the cheap food supply. For a general review it would be well to consider the tariffs west of Chicago, apart from those from Chicago to New York. The freight charge on the Chicago, Burlington and Quincey, going west, was 0·60*d.* per ton-mile, or one-seventh less than on the Chicago, Milwaukee and St. Paul Railway. But taking the tariffs east, the Lake Shore and Michigan Southern in 1883 charged only 0·364*d.* per ton-mile, and 1·098*d.* per passenger-mile, and earned a dividend at those prices of 8·11 per cent. The New York Central Railroad in 1884

charged 0·415*d.* per ton-mile, and 0·970*d.* per passenger-mile, and earned a dividend at the rate of 5·22 per cent. The Pennsylvania in 1884 charged 0·402*d.* per ton-mile, and 1·129*d.* per passenger-mile, and earned a 7 per cent. dividend. But the great reduction in the working expenses of these lines since 1872 was the most remarkable feature of all. In that year the cost of moving 1 ton of freight on the Chicago, Burlington and Quincey Railroad was 0·65*d.*, but in 1883 the total charge was 0·60*d.* In 1872 the working cost of 1 ton-mile of freight on the Lake Shore was 0·460*d.*, and in 1883 0·226*d.*; and on the New York Central in 1872 0·560*d.*, and in 1884 0·310*d.* But these were the average rates of all classes of goods and for all distances. When the question was reduced to the transport of wheat and flour it was found that the normal charge was 0·311*d.* per ton-mile between Chicago and New York; but in times of competition the charge was 0·186*d.* and lower, thus eliminating profit. The cost of working the passenger traffic had been reduced about 30 per cent. on the lines east of Chicago since 1872. This reduction in working expenses had been accomplished by the improvement of the gradients and permanent-way, by the reduction in the dead-weight of the trucks to the load carried, and by the use of more powerful locomotives, and by general good management. Mr. Gordon had given some striking figures in connection with the Chicago, Milwaukee and St. Paul Railway, and a few connected with the lines referred to might aid in the conception of the great importance and position of the American railways which had such small beginnings. The Chicago, Burlington and Quincey was 3,467 miles in length, of which 2,184 were laid with steel rails. The cost of the line had been £11,000 a mile. It had expended out of revenue £6,500,000 on construction accounts, and had a reserve of undivided profits of £2,200,000. The Pennsylvania, east of Erie and Pittsburgh, was 2,248 miles in length, and it put 36,000 tons of steel last year in all the roads which it operated; it had a reserve of undivided net profits of £3,000,000, and the whole of the interest on its funded debt was paid out of the dividends of securities which it held, and these at par value were worth £6,500,000 more than they cost. The New York Central Railroad, although only about 450 miles between its extrême termini, had a total length reduced to single track, including sidings, of 2,720, of which 1,992 were of steel weighing 65½ lbs. per yard. Thus, in estimating the length and cost per mile of railway in the United States, great care was required to ascertain what the figures really meant. Mr. Gordon had given the annual passenger traffic on the 5,000 miles of the Chicago, Mr. Atkinson.

Mr. Atkinson. Milwaukee and St. Paul Railway at 4,591,000. On the much smaller mileage of the Chicago, Burlington and Quincey, the movement was about the same; but on the 2,248 miles of the Pennsylvania 27,600,000 passengers were carried; and on the 450 miles between the termini of the New York Central 12,700,000 were carried, and there was an annual increase of 7,795,000 passenger-miles in fifteen years, and 91,200,000 ton-miles annual increase in the same period. It was to the economical working of these and other railways, and the bounties given, that the great prosperity of the United States, and the great reduction in the landed wealth of this country were due, producers in England having in addition to meet the competition of the State-aided lines of India.

Mr. Mackay. Mr. J. C. MACKAY thought the Paper by Mr. Gordon could hardly be considered to put forward the leading features for the construction, operation, and equipment of railways in newly developed countries, especially where small returns were expected. Something much less expensive than the railways described in these Papers was required, if the railways constructed therein were not to be a drag upon the State, and were to pay their way within two years of opening.

It was a great mistake to construct railways on such a lavish scale that sufficient returns from them could not be received to pay interest on the cost of construction, after deducting working expenses, within seven years of opening, as is the case on many Colonial lines. Much healthier would it be for the country and the people, if, in the first instance, Colonial Governments would only vote so much money per mile of railway as would be sufficient to construct such a railway as the revenue likely to be derived from the railway within two years of opening would place the railway on a sound financial footing. In the majority of foreign countries, where no land had to be bought, a light railway, amply sufficient for the traffic, could be constructed at so much per mile with a certainty of not exceeding the estimate, if the railway were designed by an engineer having a knowledge of the country and its needs. In the majority of instances, railways for newly developed countries were designed by men who had never set foot in that land, and who were ignorant of the ways of the country and the needs of its inhabitants. In dealing with this question it was manifestly unfair to take as a standard the pioneer railways of North America, where as soon as railways reached a certain place, a town sprung up, and within a year numbered its inhabitants by thousands, and to apply the reasoning to the construction of rail-

ways in such a country as South Africa, the Transvaal, and the Orange Free State. In these latter countries centres of population were very far apart, towns did not rapidly spring up, and there was no likelihood of the country being developed with any great rapidity. The slow, cumbrous and uncertain bullock wagon has carried on the traffic in these countries until now, and all that was necessary for present requirements was to construct a railway of the capacity of this traffic, but with the certainty of its being fairly rapid and sure. The present railways of the Cape Colony had been constructed on a lavish scale with rails weighing 60 lbs. per yard, and expensive stations, some of them costing over £20,000, while the railways alone had cost £8,000 per mile. This great expenditure had been incurred for the sake of conveying one train per day, in some cases only one train every other day, and the consequence was that the revenue did not pay one-half the interest on the loan, after deducting working expenses, and the working of these lines was obliged to be carried on in such a manner that the bullock wagon successfully competed with the railways. Before railways were introduced the people were satisfied if they reached Kimberley from the coast, without any mishap on the way, in a fortnight, and merchandise was never less than a month on the road. To accommodate this traffic, and to provide for a probable increase in seven years, a railway with 30-lb. rails, with engines and rolling-stock to match, with a speed of 15 miles an hour for passenger trains and 8 miles an hour for goods trains, would have satisfied the wants of the people, would have given better communication between place and place, and would have placed the colony in a better position financially than at present. When this railway was not sufficient for the wants of the people, after it had been laid down, say seven years, and required renewal, a heavier permanent-way with heavier rolling-stock could be gradually introduced, and the lighter rails and rolling-stock could be removed to feeders for developing districts on either side of the main line and collecting traffic. In this colony, with its fifteen hundred passengers and 350 tons of goods per mile of railway per annum, a line with rails of 60 lbs. per yard, and expensive rolling-stock and stations, had been adopted. Mr. Mackay.

In countries where the towns were far apart, and where the traffic was necessarily scanty, a railway of the design mentioned by the Authors of the Papers would be prohibitive on account of the first cost, or, if constructed, would keep the country in a state of semi-bankruptcy.

The requirement of such countries, in the first instance, was a

Mr. Mackay. railway sufficient to accommodate present traffic, with rails, say, of 25 to 30 lbs. per yard, engines of 12 tons, passenger carriages of the omnibus type, and suitable goods wagons. The stations could be left for future consideration with the exception of the terminal ones, and these need only be of cheap construction. The guard would give out tickets in the train, and passengers would await its arrival at certain defined points. This would present no difficulty with carriages of the omnibus type, and the carriages being low, the expense of platforms would not be incurred. On such a railway with convenient passing places 1,000 tons per day could be passed; and in many countries of ten times the area of England, with only the population of Bristol, this railway would be sufficient to carry the traffic for many years, and the cost need not exceed £3,000 per mile; while the railway taken as a standard by the Authors would cost in these countries double the £3,000 per mile. In such a country where this railway would be put down, there was no practical reason why each store in an up-country town should not be connected with the railway. The rolling-stock, being small and light, could easily he handled by two men, and no difficulty need arise in taking a truck where a bullock wagon now went, and the goods could be unloaded at once from the truck to the store and *vice versâ*. No country was so poor that it could not possess its railway, and when it was a question of having a cheap railway or none at all, it was manifestly better to have the cheap railway. In tropical climates it was always a difficult matter to make and maintain good roads, and when once made it was not possible to substitute any other mode of conveyance for goods than the cumbrous bullock wagon toiling along at an average speed of 1 mile an hour. Something more than this was wanted for developing a country; the transport must be certain, independent of drought, fairly rapid and cheap, and this could not be accomplished in any other way than by cheap railways, and railways for such countries must be constructed in such a manner, and in such a style, that the revenue derived from them might pay interest on the cost of working and construction.

Mr. Mosse. Mr. J. R. Mosse observed that in many respects he differed from Mr. Gordon and Mr. Cuningham as to the policy adopted in the construction of railways in North America. For instance, were not freight cars, weighing 9 tons empty, even although they carried 27 tons of paying load, disadvantageous for wayside traffic? The box car of the West Shore Railroad Company, weighing 24,000 lbs., and carrying 50,000 lbs. of freight, was surely a heavier proportion of dead to paying load than usually prevailed

in England. The heavy weight of the Pulman cars, 36 to 40 tons, was also much objected to by railway managers, but public opinion compelled their use. The locomotives were very heavy for a light rail, in one instance 40,000 lbs. on one axle. The "Consolidation" engine, a common type in the United States, had a weight of 43 tons English on a wheel base of 13 feet 6 inches, quite as much as was usual in this country, and it was therefore not surprising that there should be a decided set among American engineers against light rails, and that they were now using steel rails of from 65 to 82 lbs. per yard. Naturally, also, the bridges were constructed for a weight of 1½ ton per lineal foot, or about the same load that was common here. The result therefore was, that although in the United States railways were at first very slightly constructed, the requirements of traffic had compelled American engineers to conform to English practice. Mr. Mosse.

In "locating" railways American engineers took great pains to obtain the best gradients; when engaged on the Erie Railroad in 1850, he was informed that 12 or 15 miles of line near Dunkirk, ready for the rails, on which a gradient of 80 feet per mile prevailed, had been abandoned in order to obtain a route giving a gradient of 60 feet per mile; and on the Southside Railway in Virginia, for the sake of maintaining a gradient of 1 in 300 for which the country was generally suited, the Appomatox valley was crossed by a viaduct 2,000 feet long, and from 80 to 100 feet high. The railway from Reading to Philadelphia, 98½ miles, was laid out without any gradient against the trade, and in 1883, it carried 18,000,000 passengers, and nearly 20,000,000 tons of goods and minerals, the coal being discharged on twenty-three wharves on which there were 35 miles of sidings.

The average rate per passenger was	cents.	1·987	= 1*d.*
" " ton goods per mile	"	2·01	= 1*d.*
" " " coal "	"	1·40	= ¾*d.* nearly.

The reduction in a gradient of $\frac{5}{100}$ feet per 100 feet in length, per degree of curvature, was a common rule in America, giving good results. The trestle-work was always made from green wood, and was therefore very perishable; and unless unusually high, it was always filled in with earth after the line was opened; the few trains at first run on western railways, enabled this to be done better than was possible in more populous countries.

Up to 1853 there were very few iron railway bridges, but box girders were sent by Sir William Fairbairn to Nova Scotia, about 1855, and soon afterwards Warren girders of 100-feet span were

Mr. Mosse. sent by the late Mr. Charles May to New Brunswick, so that he doubted whether the "pin system" had priority in the United States over England. The pieces forming the pin-system girders were easier of transport than those of riveted girders, and the difficulty of riveting was avoided. Of three riveters sent from London to erect a large bridge in Ceylon, only one proved satisfactory, the other two, who were paid six months' wages in addition to their passages to and from England, only worked some six weeks. The load taken by the "Consolidated engine," on a gradient of 1 in 22·2, showed that the adhesion was about $\frac{1}{8}$ of the weight on the driving wheels, the bank locomotives, designed especially for the Kaugaunava incline on the Ceylon Railway of 1 in 45, had developed under favourable circumstances an adhesion of $\frac{1}{6 \cdot 5}$, and this was the highest adhesion of which he had personal experience. The paying load taken up this gradient of 1 in 22·2 was so small that it suggested the question, what sum could be profitably spent in improving this gradient? Taking the American ton at 2,000 lbs. the figures given on p. 115 were as follow:—

	Tons.
Weight of engine on drivers	51
„ „ front truck	7
„ tender when full	25
	—
Total weight of engine and tender	83

To give the greatest proportion of paying load, assume it to be $\frac{2}{3}$ of the weight of the train—then

Weight of cars, say, tons	47	
„ paying load	93	
	—	140
		—
		223

Adhesion about $\frac{1}{8}$; that was, paying load = engine and tender 83 × $1\frac{1}{8}$ tons = 93 tons; or taking the total dead load, 83 + 47 = 130 tons; then paying load = dead load 130 × 71 per cent., and this at a speed of only $4\frac{1}{2}$ miles per hour, which was a very unsatisfactory result. With an adhesion of $\frac{1}{8}$ this engine would haul about 2,000 tons on a level, or fourteen times the load taken up 1 in 22·2.

The cost of the Intercolonial Railway in Canada was £8,600 per mile, and single lines having but small traffic could, whether in England or abroad, be made through an easy country for that sum,

and when the cost of parliamentary expenses, land, bridging, large stations, and accommodation works required in this country but not necessary in America, were eliminated, and when the class of work common in each country was considered, he believed that railways were constructed quite as economically and more substantially in England than in the United States. As regarded the rising of the rails mentioned in his Paper, he would remark, that in Canada a thaw usually took place in January, with a southerly wind and a very heavy rainfall; within a few hours the wind became north, the temperature fell to zero, the trees were covered with icicles, and the rain which had been unable to run off from the cuttings fast enough, had formed ice 2 feet thick over the rails. Mr. Mosse.

The satisfactory working of locomotives on the Ceylon Railway of 5½ feet gauge, round curves of 330 to 420 feet radius on a gradient of 1 in 44, was a matter of much interest and importance, it having often been asserted by the advocates of the narrow gauge that such curves were impracticable. In fact, on a railway in Queensland a gauge of 3½ feet instead of the 4 feet 8½ inches gauge had been adopted in order to use curves of 5 chains instead of 8 chains radius. The experience of the Ceylon Railway had shown that this change of gauge was unnecessary; that with bogie-framed trucks curves of 400-feet radius could be safely used; that difficult country could thus be safely traversed without incurring the evil of a break of gauge, and that as regarded the metre gauge, the alleged saving on bridges, earthwork, and other construction was altogether illusory.

Mr. Ridings. Mr. H. S. Ridings was persuaded of the false economy of imperfect plate-laying; and probably few persons had suffered more from the American practice of rapid "track-laying" than he had. Not long since, when superintending the construction of the permanent-way of a railway in South America, the representative of the company offered the foreman "track-layer" so many hundred dollars if the "track" were laid to a certain point, so that a locomotive could run over it by a certain date. After that promise he had no more control over the work of that section than if he had been merely a casual spectator; but if the centre and level stakes had not been placed well in advance of the "track-layers" by the engineer the consequences to the latter might have been very serious. It was a section of the line requiring great care, being on a gradient of 1 in 26, with sharp curves. The American process of running up the construction train to near the end of the track, dumping off material at each side, &c., was carried out.

Mr. Ridings. The curving was done *in situ* in the rudest and most imperfect way, namely, by placing wooden blocks under the ends of the rails, and then getting eight or ten men to jump upon them. Thus the middle was bent too much, and the ends not bent at all, and in many cases the iron having received no permanent set, after a time became nearly straight again. But then it was a decidedly quick way of getting round the curves.

After the traffic had been opened for a short time, other rails were carefully bent to the proper curvature, and put in gradually as the traffic allowed. It was needless to say that there was no economy in the process thus described, but very much the reverse; and from an engineering point of view there never was economy in hurried, careless plate-laying.

A good deal had been written about the economy of using American chilled disk car-wheels; but these statements had not been always borne out by experience, and he had found them to be very fallacious, with regard to railways under his supervision in South America. On these lines the heavy mineral down traffic required the constant use of the brakes on every wheel for many miles. In such cases flats were worn, and the chilled disk-wheels could not be turned in the lathe like steel-tired spoke-wheels. These wheels had a great advantage over the others, because the constant friction of the brakes raised the temperature of the latter much more than of the former, and when the train emerged from the hot close valleys of the interior to descend the final incline scarped out of the rocky side of the coast-hill, it was suddenly met by a cold sea breeze, which, playing on the very hot, brittle, cast-iron disk-wheels, in many cases caused fractures, and endangered the safety of the whole train; this again was anything but an economical result. The chilled American wheels were all gradually changed for English steel-tired spoke-wheels, which lasted longer and were safer.

The ordinary central buffer couplings of American platform freight-cars were by no means economical. The buffer part of them could not be made so strong to resist "telescoping," as in the case of the buffers of English wagons, and they were constantly undergoing repairs from this cause. The coupling was destructive to the hands and lives of the brakesmen. As an instance of this, he was one day standing next the traffic superintendent when a freight-train arrived. One of the brakesmen came forward, took a small paper parcel out of his pocket and handed it to the superintendent; it contained a part of his first finger, which had been chopped off when coupling up a car at an

intermediate station. There were many far worse accidents than this due to the same cause. Mr. Ridings.

As regarded making short cuttings through rocky spurs projecting from the side of a mountain along which a railway was being constructed, he had found the following method expeditious and also truly economical. On the centre line of the railway, at the highest point of the spur, a vertical shaft, just large enough for a miner to work in, was sunk to formation level; from this point two galleries were driven at the proper gradient. The ends of these galleries were charged with the proper quantity of blasting-powder, the patent fuze laid so as to ensure synchronous explosion in both, and the galleries and shaft were carefully tamped. The explosion generally thoroughly broke up the rock for the whole length of the cutting, which was then rapidly cleared out, and the sides finished off.

In making preliminary surveys in mountainous districts, it would be found advantageous to use a large-sized aneroid for ascertaining the height of the "saddles" over which the line must evidently go, and an angular instrument with a micrometer eye-piece for estimating distances; with these, by making an allowance for curvature, according to the nature of the ground, an approximate idea could be very rapidly formed of the best "location" of the line, and of the gradients which could be used. The practice of American engineers in laying out curves, taking cross-sections, and in keeping level-books, decidedly saved much time on surveys in undeveloped countries.

Mr. JOHN ROBINSON, of Barry, Cardiff, observed that although railways in North America were made at a cheaper rate per mile than in England or Europe, the cost was really greater when the quantity and quality of the work were taken into consideration. Many of the American railways being for a single line of way, and the land granted free, was not sufficient to account for all the difference in the cost. He had travelled over many railways in the United States, and some in Canada, and it was obvious to him that much of the economy of construction was of a kind that could only be exercised in undeveloped countries. Railway companies in England had to erect public and occupation bridges, and to form road-approaches thereto, at a cost per mile equal to a mile of railway in America, where such works, as a rule, were not absolutely necessary. Again, the outlay for roadside station accommodation, walling and fencing there, was little compared with what it was here; whilst levers and interlocking apparatus for signals and switches, which were necessary for the safe working of trains here, Mr. Robinson.

Mr. Robinson. had not generally become so there. Timber, since it was abundant in America, was very properly utilized to a large extent in the structures. Though locomotives with bogie-trucks were almost universal in the United States, they were also made and used on English and on foreign and Colonial railways. When in South America and the Australian colonies, he noticed that a preference was given on some lines for rolling-stock with bogie-trucks, and he thought English manufacturers would do well to study the economical production of such. With regard to steep gradients, it was the practice of English engineers to round off the angles formed by the meeting of the two gradients with a parabolic vertical curve, and to show it on the working section, making the offsets or heights to formation at pegs, proportional to the squares of the distances. He should be glad to know what was the quantity of ballast for a single line of way where three thousand sleepers to a milo were laid. On the northern railways of Queensland, two thousand six hundred and forty sleepers were laid to a mile in some places, but only 523 cubic yards of ballast, the gauge of the line being 3 feet 6 inches. Where timber was plentiful and good ballast scarce, a greater number of sleepers than usual might be laid, to compensate for deficiency of ballasting; but given plenty of good ballast and sleepers, what were the best proportions to adopt per mile? A good road for heavy traffic could be made with two thousand sleepers and 5,000 cubic yards of ballast per mile on a line, with a gauge of 4 feet 8½ inches. Respecting earthworks, on a line of railway which he had constructed in India, the embankments were paid for by the railway company, but not the cuttings, the former being larger in quantity. But the coolies, who executed the work with baskets, were paid for both embankments and cuttings, because the material from the cuttings was cast out to spoil, and the embankments were formed from side-trenches. The sub-contracting system in India, as regarded earthworks, appeared therefore to correspond somewhat with that of the larger contracts in America.

Mr. Smith. Mr. Marcus Smith remarked that the statement in the Paper by Mr. E. B. Dorsey, read before the American Society of Engineers, respecting the comparative cost of construction and working expenses of "English and American railroads,"[1] was one of those *primâ facie* conclusions arrived at by simply dividing the capital account by the mileage constructed in each case, without inquiring into the different circumstances which largely affected the capital

[1] Transactions of the American Society of Civil Engineers. Vol. xv. p. 1.

account, irrespective of any difference between the American and English practice of construction. Such statements were calculated to mislead the public, and were eagerly repeated by speculators seeking concessions, contracts and subsidies for the construction and operation of railways in foreign countries. Mr. Smith.

The Continent of North America, as regarded natural facilities for railway construction, might be divided into three zones. These were—

I. The Atlantic seaboard or zone commencing near the Gulf of Mexico, and extending parallel to the coast in a north-east direction to the shores of Labrador; and in breadth reaching from the Atlantic coast to Hudson's Bay and the north-western extremity of the great lakes, where it touched the prairie.

II. The Pacific or mountain zone on the opposite side of the Continent parallel to the Pacific coast in a general north-west direction up to Behring Strait, and extending in breadth from the coast across the several mountain ranges to the plains, touching the north-eastern slopes of the Rocky Mountains.

III. Between these the great central, fertile zone, extending from the Gulf of Mexico north-westward to 60° north latitude, where it was lost in the wilds of the Arctic regions. This zone was wide at its Atlantic end, embracing a large proportion of the Southern States; thence northward it included the Western States and territories of the plains, and the north-west territories of the Dominion of Canada.

The Atlantic zone, in its natural features and facilities for railway construction, might not inaptly be described as a vast expansion of Great Britain in every direction, horizontally and vertically. Its mountains were higher, its rivers and valleys longer and wider, its plains and lake basins of great extent—everything was on a grand scale; but he believed the facilities for economical construction were greater than in Great Britain, as he thought would be seen by a few examples of the main trunk lines. The Intercolonial Railway commenced on the Atlantic coast at Halifax, Nova Scotia, and extended to the River St. Lawrence at Quebec, crossing a country analogous to that of the American lines farther south; and the facilities for economical construction were certainly not greater than for the latter. It was a single-track railway with the usual sidings at stations. Its length, including branches, was 867½ miles, and the average cost of construction £8,963 per mile, that of the rolling-stock being £1,406 per mile. It was designed by, and constructed under the superintendence of, English and Canadian engineers on the model

Mr. Smith. of an English railway, and was generally acknowledged to be the most solidly constructed railway on the Continent of America. The rails were at first laid to a 5 feet 6 inches gauge, but they had since been altered to the now standard gauge of 4 feet 8½ inches. The maximum gradient was 1 in 100, and the sharpest curve 4° (1,433-feet radius). The cuttings were 22 feet, and the embankments 18 feet wide at formation level, with slopes well trimmed to an angle of permanent repose according to the nature of the material. It was well ballasted, and the bridges and culverts, with two or three exceptions, were of stone and iron. The stonework of the bridges and culverts was well executed ashlar masonry, a large portion of it being granite or kindred crystalline rock. The culverts under 10-feet span were faced with broken coarse ashlar. Cast-iron pipes 3 feet in diameter were used for culverts under public roads, finished at the ends with masonry. Of the last 500 miles of the main line between Truro, Nova Scotia and Rivière du Loup, Quebec, on the St. Lawrence, the following were the average quantities per mile of the principal works executed: earth excavation per mile, 30,110 cubic yards; rock, 2,900 cubic yards; and masonry, 401 cubic yards. The total clearing and grubbing of forest was 5,162 acres, and the length of cast-iron pipe culverts was 2,188 lineal feet. There were many iron truss bridges with spans varying from 80 feet to 200 feet.[1]

It was difficult to arrive at the actual cost of construction of an American railroad from the returns of the company, as the financial statement generally included construction and rolling-stock in one item for the whole mileage in operation, while a large proportion of the mileage might be leased lines constructed by other companies, for which the rolling-stock only was furnished or maintained by the lessees. Moreover, an American railway was generally opened for traffic when the works were very incomplete, many of them temporary, and it was only after some years, when such works were renewed or otherwise brought into good condition, that a fair comparative estimate could be made of its cost of construction with that of other lines. The following, gleaned from "Poor's Manual of Railroads," 1885, was the approximate cost of construction of some of the main trunk lines in the United States of America, which at this date were assumed to be in a state of efficiency equal to that of the Intercolonial Railway.

[1] "Intercolonial Railway," by Sandford Fleming, M. Inst. C.E.

New York Central and Hudson River Railroad.—With branches and leased lines, total 993·29 miles. Mr. Smith.

	£.
Dividing the capital stock of all the lines by the total mileage gave per mile	35,707
Deduct rolling stock, say	1,500
Cost of construction per mile	34,207

Of this there was an additional mileage of track on second, third, and fourth tracks, aggregating 1,129·75 miles; sidings 579·86 miles.

Baltimore and Ohio Railroad.—Main line and branches owned by the company 457·75 miles (in 1884). Of this length 285 miles were double track.

	£.	
Cost per mile	26,325	
Deduct rolling stock, say	1,500	
Cost of constructing works	24,825	per mile.

These railways were some of the best constructed on the American continent, and crossed some of the most difficult country between the Atlantic seaboard and the interior plains; and as the Intercolonial was constructed in every respect like an English railway, save the station-buildings, which were of framed timber, and the rails of the flat-footed pattern laid without cast-iron chairs, it was obvious that the Atlantic zone on an average afforded fully as good, if not better, natural facilities for economical railway construction than Great Britain, irrespective of climate or the natural products, such as timber, so largely used in construction in America, and the cost of which was much less there than in England.

There were greater natural difficulties for the construction of railways in the Pacific or mountain zone than in the last described; but on lines crossing the entire belt, like the Union and the Central Pacific Railroads, the average cost of construction was much reduced by exceptional facilities on the high plateau between the Rocky Mountains and the Sierra Nevada ranges. This plateau was of great breadth; the Central Pacific trains took a whole day to cross the Humboldt plain or valley, where the works were very light. The plateau became narrower northward and more broken up by spurs from the main ranges of mountains, so the Canadian Pacific Railway did not derive much benefit from it.

Mr. Smith. The Government of the Dominion of Canada constructed 213 miles of the Canadian Pacific Railway from the Pacific coast to the interior plateau at Lake Kamloops, crossing the Cascade Mountains by the cañons of the Fraser River, which comprised much of the heaviest work on the whole line, including some twenty tunnels through granite and hard crystalline rock aggregating 1¾ mile in length. This was a single-track line laid with flat steel rails weighing 58 lbs. per yard, and fairly ballasted. The cuttings were 22 feet, and the embankments 17 feet wide at formation level. There was only one iron bridge (over the Fraser River), a cantilever of three spans, the centre span 300 feet, and the end spans 106 feet each, set on abutments and piers of granite-ashlar masonry between 100 and 200 feet above the level of the river. All the other bridges, of which there were a great number aggregating several miles in length, were of timber, Howe-truss pattern or trestle. There was very little masonry, chiefly retaining-walls, but a large amount of piling on the section next the Pacific coast 85 miles in length. The maximum gradient was 1·10 per 100, and the sharpest curve 9° (637-feet radius). The average cost of construction, exclusive of rolling-stock, and the cost of engineering and administration, was £12,400 per mile.

Central Pacific Railroad.—Main line and branches in operation, 1,254¼ miles.

This was a single-track line crossing the same ranges as the Canadian Pacific Railway, and the works were similar in character, but the American line had the advantage of a drier climate, in some parts arid, so that the bridging was much less. The steeper gradients were 120 feet per mile, and there were many 10° curves (573-feet radius); there was very little ballast on the line. The average cost of construction was £23,330 per mile, exclusive of rolling-stock. The excessive cost over a similar line in Canada was no doubt in a great measure due to the haste with which the works were conducted, regardless of cost, before the country had been thoroughly examined and the most suitable course for the line determined. Sensational telegrams were constantly sent over the country describing exultingly the rate of progress, and more credit was given to rapidity of execution than to good work. The same tactics were employed by the Canadian Pacific Railway Company, with similar results.

There was an extraordinary difference in the facilities for economical railway construction between the central or prairie region and the other two regions. It was a vast plain, rising gradually, or in steps, from a few feet above sea-level to the

slopes of the Rocky Mountains, 2,000 to 4,000 feet above that level. It was intersected by a few large rivers and their affluents, at wide distances apart, falling from the centre of the Continent southward into the Gulf of Mexico, and northward into Hudson's Bay and the Arctic Ocean. The natural surface of the ground afforded exceptional facilities for the economical construction of railways, and though the timber used for bridging and building had in some parts to be brought from long distances, yet, the bridges being so few, little was required, and that did not materially affect the average cost per mile. A contract for 200 miles from Red River, Manitoba, westward, was let by the Dominion Government, and partly constructed, when the line was handed over to the Canadian Pacific Railway Company. The average cost of the bridging and level-crossings together did not exceed £25 per mile, and the total cost of constructing all the works £2,000 per mile, exclusive of rolling-stock. The cost of the permanent-way was fully one-half of the whole. On the east side of the Red River the Dominion Government constructed a length of 76 miles, about two-thirds being in prairie, the remainder extending into the Laurentian or Huronian formation, comprising a considerable quantity of rock and morass. The average cost of construction was £3,020 per mile. The cuttings were 22 feet, and the embankments 15 feet wide at formation level; but there were very few cuttings. The work was chiefly low embankment, made with shovel and barrow from side-ditches. There were 1,500 cubic yards of ballast put on per mile. The station-buildings were of framed timber, and the line was enclosed with barbed wire fencing, fixed to timber posts. No masonry nor brickwork was used. In the United States the Americans made the embankments in this region narrower, never exceeding 14 feet wide, and they seldom used ballast. Thousands of miles had been thus constructed at a cost of less than £2,500 per mile; it seldom exceeded £4,000, and the mileage was rapidly increasing as the lines were being extended into the north-west territories of the Dominion of Canada. The low cost of construction in this region, and the large mileage, had the effect of very considerably reducing the average cost per mile, taking the whole Continent together. Mr. Smith.

He had thought it necessary to give these details, as it appeared very desirable that all the circumstances affecting the cost of construction in Great Britain and in North America should be contrasted.

It appeared from the above that:—

Mr. Smith. 1. The physical features of the Continent of North America, together with the abundance and cheapness of timber so largely used there, afforded on the average better facilities for the economical construction of railways than Great Britain.

2. It was well known that the parliamentary and other preliminary expenses were much heavier in England than in America.

3. The cost of land for the right of way, often comprising valuable buildings in England, was very great, while on the Continent of America it was so small that it had no appreciable effect on the average cost of a mile of railway; and often free grants of large tracts were given by the State, so that it became an asset instead of a liability.

4. Great Britain, being densely populated, valuable houses and buildings were often situated in the most suitable position for the railway line. To avoid these the line was forced into heavy cuttings, tunnels, or bridging, so that the engineers had not the same facilities for locating the line where it could be most economically constructed that they had in America, especially in the interior.

5. The enormous amount of traffic on English railways, within a very contracted space, required a great number of tracks and sidings, with many expensive station-buildings, so that the works comprised within 1 mile of railway in England would extend over a much greater length on an American railroad. Therefore a fair comparison of cost could not be made by simply taking the mileage distance between any two points on the railway.

The exceptional expenses above stated, pertaining to railway construction in England, were due to the special circumstances of the country, and not to any essential difference in the system from that practised in America. But this exceptional expenditure alone would often be greater than the total average cost of construction on many American railroads. The following were some of the essential differences in the method of construction in the two countries which mainly contributed to the great difference in cost, transitory in part only. In America much more study had been given to the location of the line, that was, selecting its position and adjusting the curves and gradients so as to obtain the most economical results, than in England; in fact, it was a prominent branch of the profession. Many experiments had been made to ascertain the resistance to the motion of trains by different gradients, and by the friction of curves and the additional moving power (and incidentally the cost) required to overcome this, beyond what was necessary on a straight and level line. The

proposition was this:—Given the section on a trial line for a railway, and the amount of traffic expected each way, it was possible to determine the necessary changes in location to limit or increase the curves, gradients, and amounts to be expended on the works, so that with suitable motive power and rolling-stock, that traffic could be conducted the most economically. Thus, on a railway where the traffic required a large number of trains to pass over the line daily, it was obvious that a considerable amount of capital might be profitably expended on the works to reduce the curves and gradients, and thereby the cost of working the trains; and this should be continued till the interest on the additional capital expended was equal to the reduction effected thereby in the cost of running the trains. On the other hand, where a small traffic was expected, say two or three trains a day, the capital expended should be reduced to the smallest amount possible, by keeping the formation of the railway as near the natural surface of the ground as practicable, by sharp curves and steep gradients. This was the system almost always followed in America, so as to secure the construction at a low cost at first, and the improvement of the line gradually as the traffic increased. But it was often carried to an injudicious extent by the lavish use of temporary works on perishable materials, and, worst of all, by bad location, which was not capable of being improved without much cost; so that after ten or more years the cost was greatly increased by renewals and improvements, much of which might have been avoided by more forethought at first. In this respect the English system of construction (waiving all preliminary expenses for right of way, &c.) was the most judicious for the main trunk lines of that country; but for lines through unoccupied or sparsely settled countries, such as the American territories and British colonies, it was far too costly, and would very quickly run any company there into bankruptcy. Mr. Smith.

Railways in America were always at first constructed for a single line of rails, called the track, and as many of them crossed long stretches of unsettled country, no fencing of any kind was erected. The width of the cuttings was generally 16 to 18 feet in rock, and rarely exceeded 20 feet in earth at formation. The slopes were taken off roughly, if at all, only so far back as to allow of their standing temporarily, and it was years after the line had been opened for traffic before they assumed a permanent inclination. Consequently landslips were of frequent occurrence, and the traffic was interrupted, which meant that the slopes, not having been taken back to the proper angle, had fallen in. The embankments were generally 14 feet wide at formation level,

Mr. Smith. but on laying the rails the angles were taken off and the material thrown into the centre to pack the sleepers and surface the rails. Ballast of some kind was afterwards brought to pack the rails up to the full height; but very little was used except where absolutely necessary in wet ground. In taking out the cuttings the contractor found it, in some cases, more profitable to waste the greater portion of the material rather than carry it to make up embankments. This waste was cast into unsightly heaps alongside the line. Earth was then "borrowed" from the sides to form the embankments. The side-ditches in Canada were neatly formed and graded, to carry the surface-water to the nearest watercourse; but in the United States they were called borrow-pits. Unsightly holes were dug, to no regular line, which formed stagnant pools. Little provision was made for drainage, and the culverts were generally too few in number and too contracted in dimensions. Therefore, in floods, the line was frequently overflowed and the works damaged. These floods were called "washouts," and were taken as matters of course and unavoidable.

In the central zone the bridges were of timber, except in crossing very large rivers such as the Mississippi and the Missouri, either of the Howe-truss type or trestles. In the west there were hundreds of miles at a stretch without 1 foot of masonry or brick-work, except incidentally some rough paving or rip-rap, to protect embankments from the wash of adjacent streams. Timber, though varying in price in different localities, was, on the average, cheap on this Continent. The cost of a Howe-truss span of 100 feet in place was £700 to £900, according to locality. Trestle-work, erected, was 1*s.* to 1*s.* 3*d.* per cubic foot. Iron in the same was 4*d.* to 5*d.* per lb. Almost all the roads crossed the railway on a level. The cost of a private road-crossing was about £10; that of a public road, from £50 to £60. The rails were of the flat-footed pattern; they were laid without chairs, joined at the ends with fish-plates, and fastened to the sleepers with spikes. The sleepers (called ties in Canada) were 8 feet long, 6 inches deep, with a top and bottom bearing-surface not less than 6 inches wide. They were mostly hewed from trees of proper size; those sawed from large logs were not so good. They were laid 2 feet to 2 feet 6 inches apart, from centre to centre, and their cost was 10*d.* to 1*s.* 6*d.* each, according to locality.

Way-stations were placed 8, 12, or 16 miles apart at first, and intermediates were added as required by increase of population. They were of framed timber. The cost of an ordinary or section

station was about £300; that of a standard station, one with tank, &c., for water-supply, was from £400 to £500. Terminal stations, and those with turntables and machine-shops, were generally of brick or stone. Mr. Smith.

He thought that in addition to good, if not exceptional, natural facilities, the low cost of railways in America was effected by using very steep gradients and sharp curves, so that the formation line might conform as nearly as possible to the natural surface of the ground. Then the road-bed was made as narrow as consistent with safety; the slopes were left untrimmed, and little if any ballast was used, which from the comparative dryness of the climate could in a great measure be dispensed with. The bridges and other structures were built of timber, which was plentiful and cheap; but they required renewing every ten or twelve years. The railway thus constructed was rough and unsightly, and with the sharp curves and unevenness of the rails would be utterly impracticable for an English engine. But the American bogie-engine, with its flexible frame, short wheel-base, and easy play in gauge, accommodated itself readily to curves down to 400-feet, or even 300-feet radius, and to any unevenness of rails, as easily as a three-legged stool to an uneven floor. This was the chief factor which, with kindred rolling-stock set loosely on four-wheeled trucks, had effected so large an advance in railway enterprise on the American continent, by making cheap railways workable and profitable, thus powerfully assisting in the rapid settlement and development of the natural resources of the country. This kind of engine was also of great assistance in construction, as temporary tracks could be laid on the surface of the ground without any grading, but only surfaced with a few shovelfuls of earth, or packed up with sleepers, over which trains could be taken with supplies, and materials for the permanent works. In the lower sections of the Canadian Pacific Railway, near the Pacific coast, long stretches of flats were subject to overflow by the floods of the Fraser River to a depth of 6 to 10 feet. The embankments over these portions were formed in some places by first erecting temporary trestle-work from timber growing alongside, over which the trains loaded with earth from distant points were run; and the earth was ploughed off the flat cars at one course, the plough being made the width of the car, and drawn over the whole length of the train by a cable attached to the engine. In other places a narrow embankment was made on which the rails were laid, and the trains were run upon them with earth brought from a distance, which was then ploughed off; the

Mr. Smith. track was next packed up 6 or 8 inches, and the process repeated till the embankment was raised to the proper height; but this was found a much more expensive process than by temporary trestling. Where the line crossed broad streams the bridges were put up first, and the embankment was raised up to the bridge-level by inclines, varying from 1 in 20 to 1 in 60. In approaching such places the bogie would take a run to get up speed and get over the incline easily. He had known construction-trains to attain a speed of more than 20 miles an hour, on a track which to look at seemed dangerous for a hand-car. The rails for the permanent-way were generally allowed to be used for construction, and many of them were badly used, but it enabled the work to be done cheaper.

In the rapid construction of the Union and Central Pacific Railroads, and, later, the Canadian Pacific Railway, much more admiration was evoked than the cases merited. The open nature of the country admitted of a large number of men being put on and supplied with necessaries without much difficulty. He had travelled thousands of miles in a buckboard, a vehicle made of a few planks joined together and set on an axle, with a pair of wheels at each end, and a raised seat in the middle for the driver, across the prairie by compass without ever being on a road; there were no roads in the country at that time, only trails. For hundreds of miles together the railway was light embankment, from 1 foot to 4 or 5 feet high, with only occasional lengths of heavier work, or a bridge. This embankment, being only 12 or 14 feet wide, could be thrown up very rapidly with simply a wheelbarrow and shovel. After this had been made 50 or 100 miles in advance, track-laying was commenced; sleepers and rails were brought to the starting-point. The former, loaded in wagons drawn by four horses, were sent in advance, distributing the sleepers on the embankment 4 to 6 feet apart. Trollies loaded with rails followed, the men laying the rails down on the sleepers, and joining them at the ends by fish-plates with one or two bolts in each, and then spiking them to gauge. In this state the track presented a very rough appearance; it was neither lined nor levelled, yet the bogie-engine, with loads of rails and sleepers, followed close on the heels of the track-layers, always bringing a good supply of rails and sleepers to the front; such a road would be impracticable for an English engine. In this way 3 miles a day or more of track would be laid from one end, but then it was not much more than half finished. Following these was a train with supplementary sleepers, spikes, &c., and a large gang of men who

put in the sleepers to make up the full number, straighten the track, and pack it with earth from the top angles of the embankment, so as to bring it into a condition to allow better speed for the trains. When it was said that 6 miles of track had been laid in a day, it was not true, as the work was then only half finished, the rails being merely thrown down and linked together on a sufficient number of ties to allow trollies or light trains to pass over slowly—unless the work was going on from more than one end. Mr. Smith.

In mountainous or rugged broken country, the rate of construction was governed by the number of men who could be supplied with plant and food. There was nothing peculiar or ingenious in American practice, except that a good deal of temporary cart-road and rough railway-track was made in advance; over the latter the bogie did good service.

Economy in rolling-stock and in operating the railways was mainly effected in America by getting all the engines and rolling-stock reduced to a standard type, or to as few differences as possible, so that all the parts could be manufactured in large quantities and be interchangeable. The Baldwin engine, Philadelphia, had for some years been in much favour. A few years ago a mechanical engineer, from one of the largest establishments in England for manufacturing locomotive engines, had told him that he was astonished at the rapidity with which these were turned out in America, owing to their being all of one type. One a week would be turned out complete; while in the English shops which he had lately left, it would take several weeks to accomplish this.

In conclusion, he wished strongly to impress upon his fellow members the necessity of informing themselves of all methods of constructing and operating railways, by which the cost could be materially reduced, otherwise they would lose their hold on public estimation. No matter if the railway was inferior, provided it could be worked satisfactorily and profitably. In sparsely settled countries of great extent of surface, like the colonies, the people could not afford the luxury of a first-class English railway, and would not pay for it. They wanted the cheapest possible railways to help them to colonize and develop the natural resources of their vast territories.

Professor G. L. Vose remarked that the question of how much to spend in building a railway, had in general been a very simple one in the United States. The question had not been, Shall an expensive road, or a cheap road be made (using the word cheap as used in England), but rather, Shall a cheap road be made or no Professor Vose.

Professor Vose. road at all? Had such doctrines as were expressed by Mr. Mosse, in his "Conclusions," page 98 of the Paper, prevailed, there never would have been a railway system to discuss, nor would the great interior grain-producing region of the United States ever have been opened up. Mr. Mosse had not only utterly failed to appreciate the railway problem as it was in America, but he made an entirely incorrect statement in saying that "It was customary in the United States up to the year 1860, if not later, to open railways at the least first cost, regardless of the large and expensive additions that would ultimately be required, as well as of the increased working expenses entailed in the meantime." Not only were many of the American roads built before 1860 well made at the outset; but in no country had so much attention been paid to studying the economic value of grades and curves, and of determining the most judicious outlay at the first, all things considered, as in the United States: and he was glad to find, by Mr. Cuningham's Paper, that upon the Canadian Pacific Railway the very features, so long employed by the engineers of the United States, had been adopted, namely steep grades, compensated for curves, wooden bridges, and the use of the standard engines made by the Baldwin Locomotive works. Mr. Gordon's Paper seemed to be a very valuable one, and his quotations from Mr. Whittemore expressed correctly the general sentiments of American engineers.

Mr. Wellington. Mr. A. M. WELLINGTON remarked that Mr. Gordon's Paper, in the main gave a correct and clear idea of American practice. Some errors of detail were but natural however in a summary of practice, in which an engineer had not himself been trained, and it might be well to correct these before treating of the broader question raised by the Paper. Not only the Louisville and Nashville, but all the southern, companies had been preparing for some time to reduce the gauge from 5 feet to the standard gauge, and in June 1886 some 13,000 miles would be changed, bringing the entire American railway system, with the exception of a very small percentage of narrow-gauge roads, to either 4 feet 8½ inches or 4 feet 9 inches. The latter was an unfortunate relic of the early confusion of gauges, which continued chiefly because it did not in practice impede interchange of traffic. Practically no new narrow-gauge lines were now built, while every year a large narrow-gauge mileage was changed to standard gauge. It was but a matter of a few years when the former would disappear. The standard freight-car axle was not by any means in universal use, although more nearly so than any other standard. The standard wheel-tread shown in Fig. 1, page 57, had been objected to, probably because it

was feared to adopt a perfectly cylindrical tread. With very slight modification it would probably be adopted eventually, but the rail section shown with it had never even been proposed as a standard officially. The corner was more rounded than general American sentiment approved. While the truck, Fig. 2, correctly represented the best tendencies of American practice it was very doubtful if that or any other one design would ever become a universal standard, or even if it was desirable that it should, owing to the diversity in the load thrown on it. The "three-truck freight car," Fig. 3, was still a mere experiment, in no sense typical of American practice, and in limited and probably decreasing use. Either the Miller or Janney automatic passenger couplers were in universal rather than in "extensive" use. One other type, the Conell, had recently obtained some favour, but with insignificant exceptions no passenger cars now ran without both automatic couplers and automatic brakes. It was apparently but a matter of a few years when both automatic couplers and brakes would be in general use in freight-cars. The types of American locomotives, Figs. 4, 5, and 6, were apparently taken from some bridge specification, in which (very properly) maximum wheel-loads were assumed. They were far heavier than the more usual engines of each type. The range of ordinary practice might be considered to be more fairly given in the following brief Table, in which the engines noted as "standard" might be considered the typical or average size, or the one which might be assumed with most probability if the kind of engine only were specified:— Mr. Wellington.

——	Cylinders.	Drivers.	On drivers.	On truck.
"American" engines—four drivers, four truck-wheels—	Ins.	Ins.	Lbs.	Lbs.
Old standard	16 × 24	55 to 66	43,000	23,000
Present standard	17 × 24	55 „ 66	46,000	24,000
Ten-wheel engines—six drivers, four truck-wheels—				
Present standard	18 × 24	51 „ 56	61,000	19,000
Mogul engines—six drivers, two truck-wheels—				
Present standard	18 × 24	51 „ 56	66,000	12,000
Consolidation engines—eight drivers, two truck-wheels—				
Present standard	20 × 24	48 „ 50	88,000	14,000

An inch more or less of diameter of cylinder made a difference of about 3,000 lbs. in the load on the drivers in the first three

Mr. Wellington. types, and about 6,000 lbs. in the Consolidation engine. Many engines an inch larger than those above were used, but comparatively few an inch smaller. Mogul engines were being substituted to a slight but increasing extent for "Americans" for heavy passenger engines, and the Consolidation type was gaining rapidly and increasingly on all others for heavy-freight service; which meant all freight service on all but minor roads, as the attention of American managers was concentrated far more than on any other element of locomotive economy on increasing the load hauled. This necessarily involved some sacrifice of economy in fuel consumption; but the latter was properly regarded as less important. It was beyond all reasonable doubt that the average train-load of freight, if not of passengers as well, was far heavier in the United States than in England; and if it were possible to compare locomotive performances per ton of paying freight hauled, the only fair standard of ultimate economy, the American locomotives would unquestionably show a record surpassing that of the English or any other foreign locomotives. This was readily demonstrable as respected continental railways, but English railway statistics, unfortunately, did not afford the means for such comparison, since they did not give passenger- and ton-mileage. Certain contravening allowances, due to difference in average haul and other conditions, ought however properly to be made in such a comparison.

As regarded permanent-way, he was pleased to find that Mr. Gordon directed attention to a fact not always remembered in comparing the average weight of rails used in England and in America, that the excess of over 50 per cent. in the number of cross-ties or sleepers used in America justified the use of lighter rails, by giving a 60-lb. rail something like equal stiffness to that of an 80-lb. or 90-lb. rail with supports 3 feet between the centres. The same was hardly true, however, of the joints, which were accordingly a source of even greater weakness and expense in America than in England, especially as the road-bed froze in winter to a depth of from 2 to 5 feet, causing much heaving, even on the best drained and ballasted track, which could only be taken out by "shims" until the frost gave out in the spring. The Fisher bridge-joint was attracting increasing attention in America as a remedy for the undoubted mechanical defects of the fish-plate type, and he was disposed to believe it would be found an entirely satisfactory remedy, and an improvement on fish-plates for all classes of track. With the joint-difficulty corrected, an allowance of at least 20 lbs. per yard should fairly be made for the greater tie-

support in comparing the English with the American track. Very great improvements had been made in the latter in the past twenty years, and were still being made, so that while there were still thousands of miles of cheaply constructed line with poor superstructures, the best 10,000 miles of track in America was probably fully equal in condition to the best 10,000 miles in England. It was a significant fact, however, that the roads having this track would be the last to dispense with the two distinctive advantages of the American locomotive, the equalizing levers for distributing the load, and the swivelling truck or bogie. It was generally felt in America, and he believed with truth, that these peculiarities, especially the first, had much to do with the great tractive power of American engines; at any rate, whatever the cause, an adhesion of one-fourth was continually realized and worked up to in regular practice, one-third was not unfrequently realized in hauling exceptional test trains for long distances, and one-fifth was the lowest coefficient ever worked to in ordinary American freight practice (and that chiefly in winter), when any attempt was made to load engines to their full working capacity. Mr. Gordon mentioned one-fifth as the average, and he had used that average in the work on railway location to which Mr. Gordon referred; but that was based on statistics compiled in the days of iron rails, since which there had been a very great increase in the loads hauled, even by the same engines. The Lake Shore and Michigan Southern Railway had increased over 50 per cent. in ten years with no change of engine. Mr. Wellington.

He considered that Mr. Gordon, while stating nothing which was not literally true in respect to curves and grades in actual use in America, had somewhat misconceived the tendency of practice, and had materially exaggerated the freedom with which those expedients for reducing cost were resorted to. Most of the very sharp curves which he mentioned, as for instance, on the Pennsylvania Railroad, were merely in yards, when on main track at all. The true maximum of the Pennsylvania was an 8° curve (717-feet radius) instead of 345 feet. Sharper curves than this were rare in America, and a 10° curve, 573-feet radius, represented about the maximum of ordinary practice in ordinarily rough country. Such curves, with gradients properly reduced on them, were passed by all American engines with perfect ease and safety, and with very slight, if any, increase in wear and tear over a curve of twice the radius and length. Accidents which could by any possibility be traced to such curves, in the sense that they would not probably have occurred had the radius of the curve

Mr. Wellington. been twice as great, were the rarest of rare occurrences, practically unknown. Whether to use curves or not, therefore, within these limits, became a question of expense; so many trains per year, so much wear and tear per train on the one hand, so much saving in construction on the other.

Nevertheless, much sharper curves, up to 300- or 400-feet radius, were almost equally practicable; and with specially designed rolling-stock, as on the Elevated Railroads of New York, curves of 90-feet radius were readily operated with trains of four or five cars, often conveying 300 passengers with perfect smoothness and ease, and at speeds of 6 to 8 miles per hour. In the whole history of the Elevated Railroads, he was informed by the General Manager, not a single accident had occurred nor been threatened on any of these curves. Such extremes were therefore used when real necessity existed; but the reckless freedom in employing them which might be hastily inferred from Mr. Gordon's words was not common. His experience was that there was almost always a certain radius which would be found to be topographically well adapted to a given route, and this conformed to the facts of American practice. Roughly speaking, and excluding curves in yards, half the American mileage might be said to be built to a 3° or 4° maximum (1,910- to 1,433-feet radius), half the remainder to a 6° maximum (955-feet radius), half the remainder to not over 10° (573-feet radius), and only about one-eighth to sharper radii, the standard gauge maximum being about 16° (359-feet radius) which brought the cost in the roughest country within reasonable limits, and enormously below what twice the radius rendered possible; while on the other hand using any sharper radii than that best adapted to the given topographical conditions rarely saved more than an inconsiderable percentage.

On the vital matter of gradients he feared that Mr. Gordon's language was still more likely to give erroneous impressions of American practice. There had been, indeed, throughout the prairie regions of the West, very great and wasteful recklessness in employing heavy gradients, for the insufficient motive of eliminating all curves and loss of distance, a mistake which the topography tended to encourage. The best American practice, however, gave no countenance to this, but rather strove as a chief end to get low grades for a large portion of the distance, "bunching" the heavy gradients together if necessary, so as to be operated by assistant power. In that case it was economically demonstrable that the particular rate of grade used on the high grades was of minor importance, and high grades at such points were used with

some freedom; but the apparent maximum grade in this case was not the true ruling grade, fixing the weight of trains; and without allowing for this fact the apparent maximum grades, as shown in the census statistics and elsewhere, were liable to give very deceptive impressions. Mr. Wellington.

The rule governing the best American practice in respect to gradients might be best given in a general statement which he had the honour to formulate, and perhaps to some extent to disseminate, but by no means to originate:—Follow the easiest possible grades for the longest possible distances, using for that purpose such amount of distance curvature and rise and fall (not increasing the maximum grade) as may be necessary, and then pass over the intervening distances by such grades as are then found necessary. This rule was not to be taken "neat," nor applied without discretion, but assuming such discretion to be used, it would in nine cases out of ten, lead to selecting the best route for railways of any class. The Erie Railway, for example, which was one of the earliest built of American trunk lines, was laid out on this principle, and it was still a splendid example of American engineering at its best, especially when it was remembered that it was laid out through a virgin wilderness. Its nominal gradients were all "bunched," and its true ruling gradients were far lower. Mr. Gordon, he thought, did great injustice to the engineers of this line, in attributing its "chronic state of bankruptcy"—which, however, was now some years in the past—to extravagance of construction, or other engineering errors. Its misfortunes had been due almost wholly to bad management, in allowing it to become the prey of sharpers, and especially in allowing competing lines to secure control of all the available western connections except the Atlantic and Great Western. This latter was one of the most badly conceived and badly executed railway enterprises in America, having very heavy grades, and yet the longest line in existence, even between its two termini, Cleveland and Cincinnati, and New York. It had consequently helped the Erie but little, and its financial failure might have been predicted with certainty from the beginning, and might be predicted with certainty to continue to the end; but the Erie's misfortunes were due to wholly different causes, since it handled an enormous traffic at a cost which, while not as low as the lowest, was certainly very remarkable, and quite low enough to redeem the engineers who constructed both the road and the rolling-stock, as well as the present management, from all reproach. This would be seen in the following figures, giving the receipts, expenses, and

Mr. Wellington. profits per ton-mile and per passenger-mile in pence for the past eleven years:—

Year.	Per ton-mile.			Per passenger-mile.		
	Receipts.	Cost.	Profit.	Receipts.	Cost.	Profit.
	d.	d.	d.	d.	d.	d.
1874–75	0·6045	0·4790	0·1255	1·1135	0·9750	0·1385
1875–76	0·5490	0·4425	0·1065	1·1010	0·9270	0·1740
1876–77	0·4775	0·3760	0·1015	0·9420	0·7360	0·2060
1877–78	0·4865	0·3370	0·1495	1·0940	0·8465	0·2475
1878–79	0·3900	0·2805	0·1095	1·0455	0·7970	0·2485
1879–80	0·4180	0·2670	0·1510	1·0205	0·6805	0·3400
1880–81	0·4025	0·2645	0·1380	1·0080	0·6860	0·3220
1881–82	0·3745	0·2630	0·1115	0·9735	0·6225	0·3510
1882–83	0·3930	0·2660	0·1270	1·0320	0·7620	0·2700
1883–84	0·3595	0·2595	0·1000	1·0840	0·8110	0·2730
1884–85	0·3280	0·2375	0·0905	0·8940	0·7635	0·1305

He believed it was claiming far less than might be claimed to say that no European railway of any class could show as low a cost per ton-mile as the total receipts of the Erie. The notable reduction shown was largely due to increase of average train-load.

American practice, therefore, did not at all agree with the theoretical studies of Mr. de Freycinet, quoted by Mr. Gordon, to the effect that 4 per cent. grades were the most economical when crossing "rolling country," and 1·8 per cent. grades for crossing "slightly uneven and partly plain land." On the contrary, the universal judgment of qualified American engineers would be that the use of even half those gradients in such country was exceedingly bad practice, because entirely unnecessary. Low grades were the one thing which skilled American engineers always sought for, sacrificing thereto freely distance, curvature, and rise-and-fall on gentle gradients eased by long connecting vertical curves. This course usually gave not only the cheapest line to operate, but the cheapest to construct, and the comparative freedom with which heavy rates were used on "bunched" grades, where assistant power was employed, should not be allowed to produce a false impression that low ruling grades were deemed a matter of slight importance. In the one case it made a great difference in the cost of operation, and in the other not. In evidence of the slight importance of a low rate of grade on inclines worked by assistant power, he would quote the following Table from p. 143 of the former edition of his treatise on railway location:—

Mr. Wellington.

TABLE XXIV.—SHOWING the ENGINE TON-MILEAGE REQUIRED to MOVE 1 TON of NET LOAD (EX-ENGINE) 100 MILES on a LEVEL, EXCEPT for a RISE of 2,400 FEET on DIFFERENT GRADES, WORKED with ASSISTANT ENGINES. ACCORDING to the AVERAGE DAILY EXPERIENCE of AMERICAN RAILWAYS, as DETERMINED in TABLE XVII.

Rate of grade on incline, feet per mile.	Length of incline.	Length of level track.	Engine ton-mileage per ton of net load moved 100 miles		
			While on incline.	While on level track.	Total.
	Miles.	Miles.			
24	100	..	1·056	..	1·056
30	60	40	0·862	0·210	1·072
80	30	70	0·760	0·369	1·129
100	24	76	0·755	0·400	1·155
120	20	80	0·766	0·421	1·187
150	16	84	0·803	0·442	1·245
200	12	88	0·900	0·463	1·363

It would be seen that the rate of incline had an inconsiderable influence on the motive power required, for the reason, largely, that the length of the run on which large power was required decreased *pari passu* with the increase of rate, which was not the case with through grades. In this Table, moreover, it was assumed that the total length of the road remained uniform at 100 miles, whatever the rate of grade adopted for the high-grade section. This was ordinarily quite out of the question, the lower grade being usually attainable only by adding so much further development within an approximately uniform air-line distance. Assuming for example, that in the above Table 80 miles of level track was essential in any case, and that in the remaining air-line distance of 20 miles, any one of the above rates of pusher-grades, from 24 to 200 feet per mile, was obtainable, but only by development—a rather extreme assumption, but sufficient for illustration —the Table would thus read:—

Rate of grade. Feet per mile.	Length.			Engine ton-mileage per ton of net load moved between the incline.		
	Incline. Miles.	Level. Miles.	Total. Miles.	While on incline.	While on level track.	Total.
24	100	80	180	1·056	0·421	1·477
30	60	80	140	0·862	0·421	1·283
80	30	80	110	0·760	0·421	1·181
100	24	80	104	0·755	0·421	1·176
120	20	80	100	0·766	0·421	1·187
150	16	84	100	0·803	0·442	1·245
200	12	88	100	0·900	0·463	1·363

Mr. Wellington.

A remarkable example of neglect of these principles—to speak only of a line foreign to Englishmen and Americans alike—was the St. Gothard Railway, in which development to reduce grades $2\frac{1}{2}$ per cent. (132 feet per mile) was obtained by the expedient of turning spirals into the mountain, with a minimum radius of curvature of 300 metres (984 feet; 5° 50′ curve), the line otherwise following straight down the valleys. In this way the following results were obtained, in round figures:—

	North side. Silenen to Göschenen.	South side. Bodio to Flesso.
Distance by valley.	17 kilometres.	20 kilometres.
Rise	700 metres.	630 metres.
Distance by line .	26 kilometres.	$28\frac{1}{2}$ kilometres.
Maximum grade .	$2\frac{1}{2}$ per cent.	$2\frac{1}{2}$ + per cent.
Equivalent grade for line directly up the valley. .	$\frac{26}{17} = 1 \cdot 53 \times 2\frac{1}{2} = 3 \cdot 83$ p. c.	$\frac{28 \cdot 5}{20} = 1 \cdot 425 \times 2\frac{1}{2} = 3 \cdot 75$

With rolling-friction 10 lbs. per ton, adhesion $\frac{1}{5}$, and 0·7 of the total weight of engine and tender on the driving-wheels, the total load behind the tender which an engine would haul up these various grades, per ton of tractive power, was:—

On 2·5 per cent. grade	26·35
On 3·75 per cent. grade (198 feet per mile)	16·53
Showing an increase in tractive power of	$\frac{26 \cdot 35}{16 \cdot 53} = 1{,}594$

From this it would be seen that although the great expenditure for the tunnel spirals did certainly increase the hauling capacity of the engines from 1·000 to 1·594, yet as it increased the distance correspondingly from 1·000 to 1·530 or 1·425, the effective work per mile run by engines was only increased in the ratio of 1·594 : 1·425 or 1 to 1·12—a very small gain for such a very large cost. American engineers on such a line would probably have adopted a 3 per cent. or $3\frac{1}{2}$ per cent. grade, and a maximum curvature of 12° to 14° (478- to 410-feet radius). Such curves would have had a natural adaptation to the topography, which would beyond question have reduced the cost one-half, and possibly two-thirds or more, while enabling considerable development to be gained at various points in the valley without resort to any heroic expedients. Traffic manifold that of the St. Gothard Railway was carried in America over curves and grades approximating these limits, with substantially as great ease and safety as if they were considerably reduced. But the introduction of heavy through grades was a very different matter, and it was not true

that good American practice warranted the use of heavy grades and curves, without very urgent reasons. One of the great advantages of reasonable latitude in radius of curvature was that it enabled more favourable gradients, as well as lower cost, to be obtained through regions of a forbidding character. As an extreme instance, showing far sharper curves than could be encountered anywhere in the United States outside of Colorado, he might mention a bridge spiral (believed to be the only one in the world) on a narrow-gauge branch line to Georgetown, Col., a mining point high up in the mountains, which was reached by a $3\frac{1}{2}$ per cent. grade, when 5 per cent. would probably have been the lowest attainable with twice as long a minimum radius. Mr. Wellington.

His communication had extended to such a length that he must omit any comments on the extended quotations which Mr. Gordon had been good enough to make from the former edition of his treatise on the location of railways. In many matters of detail, these quotations would differ materially from what would appear in the revised edition he was engaged in preparing; but as the general principles were the same, and as the corrections of detail, if made at all, would occupy some space, he was compelled to forego them. An average engine division in the United States, however, was now nearer 120 miles than 75 miles, and showed a strong tendency to increase.

In spite of these criticisms he regarded Mr. Gordon's Paper as giving in the main a correct idea of the salient features of American practice, and the same was true of the Paper by Mr. Mosse. The concluding statement of the latter, that it was "bad both in principle and in practice" to open railways of thin but growing traffic "at the least first cost," he must dissent from. Well-constructed wooden structures in place of more costly and permanent works of iron, masonry, or earthworks, were entirely safe, if properly designed and cared for, and answered a very useful purpose in keeping down fixed charges while traffic was small, as well as in enabling better knowledge to be acquired of the real requirements, and facilitating the cheaper and more leisurely erection of the more permanent works at a later date. The same was true of a cheap temporary surface line not expected to be used for more than five to twenty years, but laid out with a view of afterwards converting it into a more costly and better line, when and if the traffic developed would justify it, and sufficing for every necessary requirement in the meantime. The best American practice emphatically sanctioned this policy when adopted with intelligence, and for good reason, and carried out

Mr. Wellington. with judgment, and it often meant all the difference between financial success and failure.

Mr. Willcocks. Mr. G. W. Willcocks thought that many large railway works carried out by English engineers, not only in the colonies and in India, but also on the Continent and in South America, were equal both in economy and efficiency to any which had been constructed in the United States. It must be borne in mind that the United States were for the most part well watered and well wooded, so that railway construction was much simplified. In such countries, however, as the Cape Colony, Natal, and the Orange Free State, through a large portion of which he had travelled for days without seeing anything in the way of timber larger than an occasional thorn tree, the question of construction assumed a different aspect. Transport and skilled labour being enormously expensive, it was essential to design works at once light and easily put together. To meet these requirements steel should as far as possible be adopted, not only in the construction of bridges but also of the rails and sleepers. With this view he submitted the following estimate:—

Cost per Mile of a Steel Road as compared with a Timber Road, Metre Gauge.

Number of sleepers taken at 1,920 per mile, say 2 feet 9 inches apart, steel permanent-way, exclusive of rails, fishplates, and bolts for fish-plates.

	Tons.		£.	s.	d.
1,920 steel sleepers 5 feet 6 inches long, with riveted clips and clipping bolts complete .	30	3s. 3d. per sleeper .	312	0	0
Freight at 15s. per ton, inland carriage £1 .	..	30 tons at 35s. per ton	52	10	0
Laying 1,760 yards . .	..	at 6d. per yard . .	44	0	0
Total	30		£408	10	0

Timber Road, exclusive of Rails, Fish-plate and Fish-plate Bolts.

	Tons.		£.	s.	d.
1,920 creosoted memel sleepers 6 feet long by 8 inches by 4 inches, 30 to the ton . . .	64	2s. 6d. each	240	0	0
Dog spikes	2½	£12 per ton	30	0	0
Freight, and inland transport .	..	66½ tons at £2	133	0	0
Laying 1,760 yards and adzing.	..	at 1s. per yard	88	0	0
Total	66½		£491	0	0

This estimate showed a saving of £82 10s. per mile in favour of steel or wrought-iron sleepers, and the difference would be even

greater if the freight and transport were more. As the life of timber sleepers in a tropical or semi-tropical country would not exceed eight years, the cost of renewal every eight years would be about £500 per mile. In Natal for the extensions, wrought-iron girders had been used instead of timber for all spans of 10 feet and over. On the old lines timber superstructures were employed up to 30 feet. Having had considerable experience in selecting routes for railways he had found that this work in a country deficient in landmarks, and of which no good maps were procurable, involved a great amount of patience and careful study. In selecting a route over a mountain pass or ridge, it would be found convenient to place the theodolite at the summit, and then to clamp it to the angle of the proposed gradient, putting in pegs at various points where the gradient struck the ground, and then "surveying in." This method, if adopted on side-lying ground, would give approximately the cheapest route for the line to take. The proposed gradient was of course easily calculated by levelling from the summit to the lowest point, and then measuring the distance. In the laying out of light railways there was a tendency to put in the curves too sharp and the gradients too steep. This course should be avoided and the line laid out in such a way that when occasion arose it could be improved without much deviation or expense. A fault, which was not uncommon in the construction of light railways, was the adoption of sharp curves running directly out of the straight line or tangent. In such cases it would be far better to make use of the parabolic or "Uebergang" curve, so that the elevation of the outside rail would increase gradually with the curve itself. This compound curve, by which a great saving of wear and tear of permanent-way was effected, was as easily set out as the ordinary simple curve or arc now so generally adopted. On long and steep gradients the creeping of the rails was often a source of great inconvenience. Mr. Willcocks.

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30 March, 1886.

EDWARD WOODS, Vice-President,
in the Chair.

The discussion upon the Papers, by Messrs. Gordon, Mosse and Cuningham, on "The Economical Construction and Working of Railways," occupied the whole evening.

*** An abstract of Mr. Dorsey's Paper, "English and American Railroads Compared," which is referred to by Mr. Gordon, and in the subsequent discussion, will be found *post*, p. 327.

6 April, 1886.

SIR FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The following Associate Members have been transferred to the class of

Members.

EDWARD CHARLES CRACKNELL.
RICHARD FUGE GRANTHAM.
WILLIAM HODGSON.
ARTHUR CAMERON HURTZIG.
FREDERICK VALENTINE.

The following Candidates have been admitted as

Students.

CLAUDE WILLIAM ATKINSON.
BENJAMIN BALL.
ALBERT BROOKS.
ALBERT PLAYER ISAAC COTTERELL.
SIDNEY PATERSON DOVE.
RICHARD JOHN DURLEY.
JOHN FRANKLIN GAGE.
ROBERT TYNDALL GIBBS.
SYDNEY WHITMORE HAMILTON.
HARRY CECIL JONES.
WILLIAM ARTHUR KERLEY.
FRANCIS HARMAN LEWIS.
HOWARD MARTINEAU.
HERBERT WILLIAM MORLEY.
FRANK OSWELL, B.A.
FRANCIS JOSEPH PIGOTT.
EDWARD PINCHING.
SYDNEY RAYMOND.
CHARLES GORDON RING.
EDWARD HUGH OCTAVIUS SANKEY, B.A.
WILLIAM SIMKINS.
RALPH HARRY STEPHENSON.
BENJAMIN EDWARD TODHUNTER.
WILLIAM GEORGE TURNBULL.
SAMUEL SUGDEN WADDINGTON.
HENRY JAMES SEATON WADE.
THOMAS ROBERT HALL WATSON.
HARRY ATCHISON WILLIS.
CHARLES DUNDAS DOVE WILSON.

The following Candidates were balloted for and duly elected as

Members.

CHARLES EDWARD EMERY.
ALEXANDER LAUDER HOGG.
MACNAMARA RUSSELL.

Associate Members.

Francis William Ashpitel, Stud. Inst. C.E.
Frederick Theodore Bagshawe, Stud. Inst. C.E.
John Frederick Evelyn Barnes.
Davis Edmondson Benson, Stud. Inst. C.E.
Ernest Augustus Brine.
Henry Augustus Brundell.
William Burch.
Leonard Burrell, Stud. Inst. C.E.
Charles Claude Carpenter.
Joseph Julius Cazimajou, B.Sc.
George Frederick Charnock, Stud. Inst. C.E.
George Charles Child.
Charles John Cole.
Stanley De Brath.
Francis Charles Dixon, Stud. Inst. C.E.
John Oliver Surtees Elmore.
William Fairley, Stud. Inst. C.E.
Charles Firth.
Gilbert Gilkes.
Thomas Edward Goodall.
Joshua Harrison Hargrave, B.A., Stud. Inst. C.E.
David Honison.
Tom Alexander Horn, Stud. Inst. C.E.
William Isaac Last, Wh.Sc.
Henry Monson.
Walter Norman.
Henry Hollinworth Parkinson, Stud. Inst. C.E.
Henry Ernest Parry.
Godfrey Bowen Partridge, Stud. Inst. C.E.
Henry Vivian Majendie Phelips, Stud. Inst. C.E.
Henry Parnham Phillips.
John Price.
Alexander Craig Renton, B.Sc.
John Simpson Roper, Stud. Inst. C.E.
James Wilmot Andreas Rose.
Frederick John Rowan.
Frederick Henry Rowling, Stud. Inst. C.E.
Henry Fillmer Rutter, Stud. Inst. C.E.
Arthur Lewis Shackleford.
Frank Holmes Stone.
Edward Augustus Stoney.
Robert Lethbridge Tapscott.
Robert Charles Taylor, Stud. Inst. C.E.
Walter Taylor, Stud. Inst. C.E.
Robert Henry Thorpe, Stud. Inst. C.E.
Arthur Henry Vesey.
George Whale.
Samuel Graham Willmott.
George Wilson.

Associates.

John Mowlem Burt.
John Thomas Wright, Major R.E.

(*Paper No. 2150.*)

Water-Purification; its Biological and Chemical Basis.

By Percy F. Frankland, Ph.D., B.Sc. (Lond.), F.C.S., F.I.C.,
Associate of the Royal School of Mines.

Although the purification of water has received much attention during the past thirty years, it is only now that the complexity of this subject is beginning to be realized.

The earliest attempts to purify water had for their object simply the clarification of the liquid, *i.e.*, the removal of suspended particles visible to the naked eye. In this purification there was

no endeavour to remove dissolved matters, and suspended particles invisible to the naked eye were not then thought of. It cannot be doubted that, in most cases, this primitive conception of water-purification has still been retained, the sole idea of the operator being to produce a liquid clear and sparkling to the eye.

The advances of chemical science caused attention to be paid to the matters present in water in the state of solution, and more particularly to those of an organic nature. In the first place, it was supposed that organic substances were capable of imparting alteration and decay to other organic substances with which they were placed in contact; this being the theory of fermentation advanced by Liebig. Thus Liebig conceived that ordinary alcoholic fermentation was brought about not by the living and growing yeast, but by the dead yeast-cells undergoing decomposition. As long as this theory was the accepted doctrine of the day, it was not surprising to find chemists attaching great importance to the organic matter in water which analysis revealed, and which was known to have been derived from decomposing vegetable and animal substances with which the water had been in contact. It was naturally supposed that such decomposing organic matter in water would tend to set up putrefactive and other injurious changes in the digestive organs through which it passed.

The theory, or rather dogma, of fermentation enunciated by Liebig, was soon broken down by the classical researches of Pasteur, by whom it was shown that the processes of fermentation and putrefaction were due not to decomposing organic matter, but to living organisms, and that living organisms were also certainly the cause of some and probably of all zymotic diseases. Under these circumstances, the organic matter present in water came to be viewed in a different light, and instead of being regarded as in itself unwholesome, it could now only be taken as affording more or less evidence of the possible presence of organisms, endowed with virulent properties. As it was further established beyond doubt, by bitter practical experience, that certain zymotic diseases—notably typhoid fever and cholera—could be communicated by means of sewage-polluted water, the chemical examination of water was prosecuted with a view of ascertaining the presence or absence of such contamination by means of the organic matter which the water was found to contain. Through refinement in the processes of chemical analysis it has, moreover, been rendered possible to discriminate with a very considerable degree of certainty between organic matter of vegetable, and that of animal origin. The detection of animal matter in water was not

supposed to carry with it *ipso facto* the certainty of danger, but in the absence of any precise knowledge concerning those organisms which produce zymotic disease, the presence of such animal matter obviously indicated the possibility of danger.

It is thus seen that in this second stage of progressive knowledge, the purity of water was at first gauged merely from a chemical point of view, and that afterwards, through the researches of Pasteur and others, it came to be understood that chemical purity was really of less importance than biological purity; but owing to the absence of any satisfactory means of examining waters biologically, the chemical standard was the only one by which they could be judged.

Under these circumstances, it was natural that means should be devised to render water as chemically pure as possible, on the assumption that the conditions which tended to improve the chemical quality, would similarly affect it biologically. This is essentially the period of the late Rivers Pollution Commission, in which so many methods of water- and sewage- purification are fully discussed by the light of chemical analysis. In these discussions, the importance of the biological side of the subject is fully recognized, but owing to the absence of any reliable methods at that time, the examination was not pursued in this direction.

It is to the vastly improved methods of biological examination that the only great step which has been made in the knowledge of the purification of water since the researches of the last Commission is to be attributed. These methods of biological examination, which are largely due to the genius of Dr. Robert Koch, of Berlin,[1] enable the merely chemical investigation of the subject of water-purification to be supplemented in a manner that was never possible before.

This method of examination is based upon principles of such exquisite simplicity, that a very brief description will suffice to render it intelligible.

The microscopic living particles known as "micro-organisms," or "microphytes," which it is the object of a biological examination to study, possess such an astonishing power of rapid multiplication when they are placed in a medium fitted for their growth, that within a very short period of time it becomes impossible to form an opinion as to the number of original organisms from which the vast population is descended.

Thus, if such micro-organisms be distributed throughout a medium suitable for their multiplication, and if each individual

[1] Mittheilungen Kaiserl. Gesundheitsamt, 1882.

organism be then immediately deprived of the possibility of movement, the number of colonies arising from the multiplication of these isolated individuals indicates the number of organisms introduced, whilst, by the nature of the colonies formed, the kinds of organisms of which the original importation consisted may be ascertained.

If the conditions here indicated can be complied with, it is obvious that all the means are at hand for determining the effect of any method of water-treatment upon these lowest forms of organic life. This imprisonment, so to speak, of each individual and its subsequent progeny, which is thus the key to the whole problem, can be readily effected by adding to a nutritive liquid, such as extract of meat, a sufficient quantity of gelatine to render the whole solid at the ordinary temperature. The process consists, in short, in taking a known volume, *e.g.* 1 cubic centimetre of water, and mixing it with a quantity of such nutritive gelatine, that has been melted at the temperature of the hand, and then pouring the mixture upon a glass plate on which it sets in the course of a few minutes to a solid mass. The plate is placed under a glass-cover, so as to protect it from dust, and is kept at a temperature of about 20° to 25° Centigrade. In the course of from three to five days the colonies, each originating from a single organism, attain such dimensions that they may be recognized and counted with the naked eye or by means of a microscope of low magnifying power.

It is thus evident that the purification of water must now be regarded from two distinct points of view—the chemical and the biological—and that whereas formerly the biological side was almost wholly of a speculative character, it is now nearly, if not quite, as tangible as the chemical side. Thus, perhaps a concrete example will most clearly illustrate how the purification of water should be regarded. Supposing that water, derived from a source which is altogether unimpeachable as regards contamination with animal matters, is yet so highly impregnated with vegetable constituents as to be objectionable for drinking-purposes, the question will arise how this water may be treated so as to render it suitable for domestic supply. In a case of this kind it is obvious that chemical purification will be of paramount importance, whilst the removal of organic life from the water will be of less pressing consequence. On the other hand, if water, which is known to have received sewage matters is to be supplied for dietetic use, and if this water, as is so often the case, is not objectionable on account of the absolute quantity of organic matter which it con-

tains, but only because of the suspicious origin of a part of this organic matter, then it is evident that in the purification of such water the point to be taken primarily into consideration, is how the organic life it contains can be reduced to a minimum.

In estimating the value of such processes of purification, it has hitherto been customary to assume that those processes which effect the greatest chemical improvement in water may also be safely considered to be biologically the most excellent; and conversely, that those processes which effect little or no reduction in the proportion of organic impurity are not calculated to be of any service in removing organized matters.

In the experiments which the Author has for some time been conducting on the removal of micro-organisms from water, the first results of which he communicated to the Royal Society in May 1885,[1] he has found that this assumed law, or at least its converse, is very far from being correct. Thus the Author discovered that some materials were capable of filtering out all the organisms in water without appreciably altering its chemical composition.

The Author's inquiry into the chemical and biological purification of water may be conveniently considered under four heads:—

1. Purification by filtration.
2. Purification by agitation with solid particles.
3. Purification by precipitation.
4. Purification by natural agencies.

I. Purification by Filtration.

Until the method of water-examination by gelatine-culture was devised, there were no available means by which the relative efficiency, for the removal of micro-organisms, of different filtering materials could be estimated on a quantitative basis.

The Author has submitted to examination, as regards their efficiency in this respect, a number of filtering materials, employing in all cases equal thicknesses of the various substances, which were also prepared in the same state of division. The filtering stratum was constructed exactly 6 inches in depth, and the filtering material was, with a few exceptions, made to pass through a sieve of 40 meshes to the linear inch. The results obtained in these experiments were:—

[1] Proceedings of the Royal Society of London, vol. xxxviii. p. 379.

Filtering material.	Efficiency.	Organisms per cubic centimetre.		Reduction per cent.	Approximate rate of filtration per square foot per hour.
		Unfiltered water.	Filtered water.		
					Gallons.
Ferruginous green-sand (from Red-hill, Surrey).	Initial . . .	80	..	100·0	..
	After thirteen days' action .	8,000	1,000	88·0	0·73
	After one month's action	1,280	780	39·0	1·14
Animal-charcoal .	Initial . . .	Too numerous to count.	..	100·0	..
	After twelve days' action .	2,800	..	100·0	0·46
	After one month's action	1,280	7,000	Increase 447·0	0·86
Iron sponge . .	Initial . . .	80	..	100·0	..
	After twelve days' action .	2,800	..	100·0	0·40
	After one month's action	1,280	2	99·8	0·45
Brick-dust (pulverized red brick) .	Initial . . .	3,000	780	76·0	..
	After five weeks' action . . .	6,000	400	93·0	0·48
Coke	Initial . . .	3,000	..	100·0	..
	After five weeks' action . . .	6,000	90	98·5	0·50

The Author has made further experiments on the efficiency of coke as a filtering material. In these experiments the filters employed were of similar construction to those already described, but an aqueous extract of garden-soil was employed instead of urine-water.

Two similar filters (*a*) and (*b*) were submitted to examination, under conditions as similar as possible:—

INITIAL EFFICIENCY (SECOND DAY).

Unfiltered water	26,000	organisms per cubic centimetre.
Filter (*a*)	0	,, ,,
Filter (*b*)	0	,, ,,

Reduction (*a*) = 100 per cent.
,, (*b*) = 100 ,,

Approximate rate of filtration (*a*) = 0·89 gallon per square foot per hour.
,, ,, (*b*) = 0·67 ,, ,,

AFTER THREE WEEKS' ACTION (TWENTY-FIRST DAY).

Unfiltered water	2,230 organisms per cubic centimetre.
Filter (*a*)	339 " "
Filter (*b*)	219 " "

Reduction (*a*) = 85 per cent.
" (*b*) = 90 "

Approximate rate of filtration (*a*) = 1·32 gallon per square foot per hour.
" " (*b*) = 1·03 " "

On comparing these latter experiments with those previously obtained, it will be seen that although the initial efficiency was in both cases the same, the greater rate of filtration which prevailed in the latter experiments caused the efficiency to deteriorate more rapidly, the filter (*a*), which was the most rapid, breaking down to a greater extent than the less rapid filter (*b*).

The unfiltered and filtered waters, respectively, were also submitted to chemical examination, at the time that the filters were exerting their greatest efficiency in the removal of micro-organisms; the results are given in the following Table, together with those obtained by the filtration of the same water through fine vegetable-charcoal, and through a mixture of fine and coarse vegetable-charcoal, respectively:—

RESULTS of ANALYSIS EXPRESSED in PARTS per 100,000.

——	Unfiltered Water.	Water from Fine Coke. A.	Water from Fine Coke. B.	Water from Fine Wood Charcoal.	Water from Coarse and Fine Wood Charcoal.
Total solids	24·80	24·60	25·00	24·68	24·64
Organic carbon	0·144	0·118	0·107	0·090	0·098
" nitrogen	0·050	0·040	0·038	0·024	0·031
Ammonia	0	0	0	0	0
Nitrogen as nitrates and nitrites	0·190	0·209	0·202	0·221	0·217
Total combined nitrogen . .	0·240	0·249	0·240	0·245	0·248
Chlorine	1·9	1·9	1·9	1·9	1·9
Temporary hardness . . .	11·3	11·3	11·3	12·5	12·3
Permanent " . . .	5·6	5·6	5·6	4·6	4·6
Total . . . "	16·9	16·9	16·9	17·1	16·9

These results show that filtration through coke exerts but an

insignificant chemical action, even when the purification from a biological point of view is complete.

Vegetable-Charcoal.—The very favourable results obtained with coke led the Author to investigate the filtering power of the still more porous vegetable- or wood-charcoal. This material was also passed through the same sieve, and employed in filters of similar construction. In the first experiment urine-water was used, with the following results:—

INITIAL EFFICIENCY (SECOND DAY).

Unfiltered water	9,700	organisms per cubic centimetre.
Water filtered through fine charcoal	0	" "

Reduction = 100 per cent.

Later experiments were made with an aqueous extract of soil, the following results being obtained:—

INITIAL EFFICIENCY (SECOND DAY).

Unfiltered water	2,898	organisms per cubic centimetre.
After filtration through fine wood-charcoal	0	" "

Reduction = 100 per cent.

Approximate rate of filtration = 0·22 gallon per square foot per hour.

AFTER ONE MONTH'S ACTION (TWENTY-NINTH DAY).

Unfiltered water	2,230	organisms per cubic centimetre.
After filtration through wood-charcoal	107	" "

Reduction = 95 per cent.

Approximate rate of filtration = 0·22 gallon per square foot per hour.

It is thus seen that the efficiency of the fine charcoal at the end of one month is less than that of the coke with the slow rate of filtration, but greater than that of the more rapid coke filters at the end of three weeks, the rate of filtration in the case of the charcoal being markedly less than in any of the coke experiments.

In order to obtain a more rapid charcoal filter, an intimate mixture was made of equal parts of coarse and of fine charcoal, the former having passed through a sieve of 9 wires by 30 wires to the square inch, and the latter through one of 40 meshes to the linear inch, and this was introduced into a glass tube, so as to form a stratum of filtering material 6 inches in depth. With this filter the following results were obtained:—

INITIAL EFFICIENCY (SECOND DAY).

Unfiltered water	26,000	organisms per cubic centimetre.
Filtered through coarse and fine charcoal	0	" "

Reduction = 100 per cent.

Approximate rate of filtration = 0·26 gallon per square foot per hour.

After Three Weeks' Action (Twenty-first Day).

Unfiltered water	2,230	organisms per cubic centimetre.
Filtered through coarse and fine charcoal	506	" "

Reduction = 77 per cent.

Approximate rate of filtration = 0·59 gallon per square foot per hour.

Thus with wood-charcoal, when the rate of filtration approaches that through coke, the improvement, from a biological point of view, is markedly less. The effect which this material has upon the chemical composition of the water, as exhibited in the above table, is greater than that of coke, but is also not very considerable.

It has generally been supposed that most filtering materials offer little or no barrier to micro-organisms, and that the latter are capable of passing without sensible obstruction through the pores of filters containing pulverized materials. These experiments, however, show that it is extremely simple to construct filters which shall possess the power of removing micro-organisms, in the first instance at least. This power is, moreover, possessed by substances which exercise scarcely any chemical action on the organic matter present in the water, *e.g.*, coke, vegetable-charcoal, and biscuit-porcelain, as well as by those which reduce both the organic and the mineral ingredients of the water to a very marked extent, like animal-charcoal and iron.

Especially noticeable is the case of vegetable-carbon, whether in the form of charcoal or of coke; this material has been generally regarded as of but little value for water-purification, owing to its chemical inactivity, but as biological filters these substances occupy a high place, and owing to their cheapness and the facility with which they may be renewed, and profitably disposed of as fuel, they are, in the Author's opinion, destined to be of great service in the purification of water.

These materials, coke and vegetable-charcoal, are also especially well fitted for use in breweries and distilleries, where it is so necessary to have a water which, though perfectly free from organic life, is at the same time free from antiseptic substances, such as iron, which militate against fermentation. Coke has already been used, at the Author's suggestion, with marked success.

These experiments, however, show most distinctly the necessity of frequent renewal, even in the case of the best filtering materials, and this is a point which, unfortunately, is too often lost sight of.

Lastly, they furnish abundant confirmation of the principle which has been long known to waterworks-engineers, viz., that what is gained in rapidity, is lost in efficiency, and *vice versâ*.

II. Purification by Agitation with Solid Particles.

This method of water-purification has recently been brought prominently before the public by Mr. W. Anderson, M. Inst. C.E., who has patented a process for agitating water with scrap-iron in a revolving cylinder. Some of the results obtained by this method have been brought before the Institution of Civil Engineers by Mr. W. Anderson[1] and Mr. G. H. Ogston, Assoc. Inst. C.E.[2] In this process, however, the purification is probably due almost entirely to chemical action, inasmuch as a portion of the iron passes into solution, and is subsequently precipitated in a settling-tank by contact with the air. This process is employed on a large scale at the Antwerp Waterworks, where it has superseded filtration through spongy iron; and on a large experimental scale it may be seen in operation at the Lee Bridge works of the East London Waterworks Company.

The Author has not himself examined this particular method of purification, but he has made a number of experiments in order to ascertain whether, and to what extent, the organized matters in water may be removed by agitation with finely-divided solid particles of various kinds.

It appeared probable, from the results of the filtration-experiments already described, that organized substances might be largely removed by mere contact with finely-divided matter. A series of experiments was consequently undertaken with a view to ascertain to what extent this was the case, and in some instances the reduction was found to be much greater than could have reasonably been anticipated.

In these experiments water containing micro-organisms was shaken up for a definite length of time with a given quantity of the finely-divided matter, which was used in the same state of subdivision as in the filters already described. The water was then allowed to subside, and the clarified water submitted to examination, as soon as possible after complete subsidence had taken place, as it appeared probable that if the organisms were

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[1] Minutes of Proceedings Inst. C.E. vol. lxxxi. p. 279. [2] *Ibid.* p. 285.

simply carried to the bottom by the subsiding particles without suffering any injury, they would rapidly again become distributed through the upper layers of water by multiplication. This supposition has been amply verified by experiment.

Agitation with Spongy Iron.—The water was shaken with one-tenth of its weight of this material for fifteen minutes. The water was allowed to subside for half-an-hour before examination.

Untreated water contained . . .	609 organisms per cubic centimetre.
After fifteen minutes' agitation .	63 " "

Reduction = 90 per cent.

On another occasion Thames water from Hampton was shaken with spongy iron for fifteen minutes, with the following results:—

Thames water	155 organisms per cubic centimetre.
After fifteen minutes' agitation .	10 " "

Reduction = 93 per cent.

Agitation with Chalk.—Urine-water was shaken for fifteen minutes with one-fiftieth of its weight of chalk, and then allowed to subside for five hours:—

Untreated water	8,000 organisms per cubic centimetre.
After agitation	270 " "

Reduction = 97 per cent.

Agitation with Animal-Charcoal.—Urine-water was shaken with one-fiftieth of its weight of animal-charcoal for fifteen minutes, and then allowed to subside for nearly five hours:—

Untreated water	8,000 organisms per cubic centimetre.
After agitation	60 " "

Reduction = 99 per cent.

Agitation with Vegetable-Charcoal.—Water containing soil-extract was shaken with one-fiftieth of its weight of ordinary wood-charcoal for fifteen minutes, and was then allowed to subside for twenty-seven hours:—

Untreated water	3,000 organisms per cubic centimetre.
After agitation	120 " "

Reduction = 96 per cent.

Agitation with Coke.—Urine-water was shaken with one-fiftieth

of its weight of fine coke for fifteen minutes, and then allowed to subside for forty-eight hours:—

Untreated water	Too numerous to be counted.
After agitation with coke . . .	None.

Reduction = 100 per cent.

Further experiments made with water containing soil-extract have shown that this process of purification is unreliable, owing apparently to the numerous conditions which are necessary for its success. In some cases the number of organisms in the clear liquid was greatly increased, this being doubtless due to a re-ascension and multiplication of those which were at first carried down. Thus in one series of experiments the following results were obtained:—

Untreated water	3,000 organisms per cubic centimetre.		
After agitation with coke and twenty-six hours' subsidence .	20,000	"	"

Further experiments of a similar nature were made, but less time (only five hours) was allowed for subsidence:—

Untreated water	655 organisms per cubic centimetre.		
After agitation with coke and five hours' subsidence	28	"	"

Reduction = 96 per cent.

Thus, although a most remarkable purification may be accomplished by this simple process of agitation with the various substances specified, yet owing to the uncertainty of its success its efficiency cannot at present be relied on.

Water was also agitated with several other substances, such as china-clay, brickdust, plaster of Paris, oxide of manganese, &c.; all of these, however, yielded unsatisfactory results.

The conclusion to be drawn from these experiments is that very porous substances like coke, animal- and vegetable-charcoal, are highly efficient in removing organized matter from water when the latter is exposed to their contact in agitation.

The removal of micro-organisms through the surface-attraction of suspended particles, naturally leads to a consideration of what takes place when the suspended particles are generated in the water itself by precipitation.

III. Purification of Water by Precipitation.

As by far the most common and most important method of water-purification dependent upon precipitation is the well-known process of Dr. Clark, the effect of this on organized matters was made

the subject of special study. With this view the Author has examined the process both in the laboratory as well as on the large scale as practised by manufacturers and by water companies.

Laboratory Experiments.—For testing the efficiency of the process on the laboratory scale, three stoppered Winchester quart bottles were taken, and to each were added 2 litres of ordinary London (Thames) water, to which a convenient proportion of organisms had been imparted by the addition of urine-water. To two of these bottles, 100 cubic centimetres of clear lime-water were added, this being calculated to remove 11·6 parts of carbonate of lime per 100,000 parts of the water. Each of these bottles was violently shaken, and the contents were then allowed to subside for eighteen hours. The bottle, to which no lime-water had been added, was tested without disturbing the precipitate, as was also the third bottle which had been left at rest in the same place as the other two. These tests showed the following numbers of organisms to be present in the water before and after treatment:—

Untreated water	85	organisms per cubic centimetre.
After eighteen hours' rest . . .	1,922	" "
Water after treatment by Clark's Process and eighteen hours' subsidence	42	" "

Reduction on original = 51 per cent.

In order to appreciate the value of the treatment by Dr. Clark's process, it is necessary that the treated waters should be compared not only with the original water, but also with the untreated water after eighteen hours' rest; for the latter obviously indicates what the condition of the water would have been at the time of examination, if no lime-water had been added. It appeared probable that, after the subsidence of the carbonate-of-lime precipitate had taken place, the organisms which had been carried down by the latter would again become distributed throughout the upper layers of the water. In order to ascertain whether this was the case or not, the same waters which had remained stoppered up and at rest, were again examined after the lapse of ten days. It was then found that the untreated as well as the softened waters contained immense numbers of organisms in their upper layers.

In another series of experiments carried out under the same conditions, excepting that twenty-one instead of eighteen hours were allowed for the subsidence of the carbonate of lime, a reduction in the number of organisms amounting to 41 per cent. was obtained.

Experiments on an Industrial Scale.—It appeared to be of great interest to ascertain what results could be obtained by Dr. Clark's process on the large scale. For this purpose the process of softening as practised at the Colne Valley Waterworks at Bushey, near Watford, was investigated, as well as the new modification of Dr. Clark's process, devised by Messrs. Gaillet and Huet, which was lately in operation at Mr. Duncan's Sugar Refinery, Clyde Wharf, Victoria Dock. The Author is indebted to Mr. Verini, of the Colne Valley Waterworks, as well as to Mr. Duncan, and Mr. Newlands, for their kindness in permitting him to carry out these experiments.

At the Colne Valley Waterworks, the hard water (see analyses given below) obtained from a deep well sunk into the Chalk, is mixed with the requisite proportion of clear lime-water, and then allowed to settle in open tanks. The subsidence is so rapid that under favourable circumstances the upper layers of water are, after three hours' time, fit for distribution. On the occasion of the Author's visit, however, boring operations were being carried on, and the water was in consequence milky, and the necessary subsidence after softening had to be increased to two days.

A perfectly representative sample of the water before softening could unfortunately not be obtained, and the number of organisms found in the untreated water is probably in excess of that which was present in the unsoftened water. The following results were obtained:—

Unsoftened water	322 organisms per cubic centimetre.
Water after softening and two days' subsidence (from main) . . .	4 " "

Reduction = 99 per cent.

In Gaillet and Huet's process, as carried out at Mr. Duncan's, the water from an artesian well, sunk into the Chalk below the London Clay, is mixed with a suitable proportion of lime-water and caustic soda, the mixture being then made to pass upwards through a tower provided with oblique diaphragms, which accelerate the precipitation of the carbonate of lime. The passage through this tower occupies a period of about two hours. Samples of the water before and after treatment, were examined with the following results:—

Well water from tanks	182 organisms per cubic centimetre.
Softened water	4 " "

Reduction = 98 per cent.

These results, and especially those obtained on the industrial

scale, conclusively prove that Clark's process is a most valuable agent for purifying water biologically, and the value of the process from a chemical point of view is illustrated by the following analyses:—

PARTS PER 100,000.

	Total Solids.	Organic Carbon.	Organic Nitrogen.	Hardness.
Caterham water-supply before softening	27·68	0·028	0·009	21·2
After softening by Dr. Clark's process.	8·80	0·015	0·003	4·4

GAILLET and HUET'S PROCESS.

	Well at Clyde Wharf, Victoria Dock.	Ditto after Softening.
Total solids	58·76	44·20
Organic carbon	0·111	0·084
" nitrogen	0·017	0·016
Ammonia	0·050	0·060
Nitrogen as nitrates and nitrites	0	0
Chlorine	16·7	17·3
Hardness { Temporary	19·8	2·4
Hardness { Permanent	8·0	6·0
Hardness { Total	27·8	8·4
Sulphuric acid	3·96	4·01
Silica	1·44	0·69
Alumina and oxide of iron	0·22	0·14
Lime	12·57	5·96
Magnesia	2·82	0·57
Potash	0·93	1·06
Soda	13·13	15·76
Carbonate of soda	0	2·0
Carbonate of lime	21·32	5·89
Carbonate of magnesia	1·43	1·20
Suspended matter:—		
Mineral	0·22	turbid
Organic	0·10	turbid
Total	0·32	turbid

On comparing the reduction of the organic matter, as indicated by chemical analysis, with the diminution in the number of micro-organisms revealed by the biological examination, it will be seen that the biological efficiency of Dr. Clark's process is markedly superior to its power as a chemical purifier. This is obviously a matter of great importance, as it shows the value of methods of precipitation in removing micro-organisms; it must, however, be borne in mind that the particular precipitation process referred to above, is carried out with the greatest care and cleanliness, and it is a rule, to which there is no exception, that satisfactory results, as regards the removal of micro-organisms, can only be

obtained when the most scrupulous care and continuous attention are given to the matter, and failure will inevitably result when such processes are not under proper supervision.

IV. Purification by Natural Agencies.

It is a matter of common knowledge that of natural waters the purest, as regards organic matter, are those which have undergone prolonged filtration through porous strata. Such waters obtained from deep wells and deep-seated springs often contain the merest trace of organic matter, which is only discoverable and capable of being quantitatively determined by the most refined analytical methods. It has also been shown by Pasteur that many of these waters are entirely destitute of organic life, or are in other words sterile.

Of a number of waters of this kind, the Author has only met with isolated samples in which absolutely no organic life was revealed by cultivation with the gelatine mixture, although many have closely approached this ideal state of things. It must, however, be remembered that the collection of natural waters of this kind in a sterile condition is fraught with great difficulty, inasmuch as the places where such waters issue are almost invariably surrounded by conditions which favour the communication of organized matters to the water. Thus the damp, earthy surfaces with which the issuing water comes in contact form a favourable seat for the development of many growths. It is probably in consequence of such contact at the surface that subterranean waters, like that of the Kent Company, are found to contain their complement, a small one only, it is true, of organic life capable of growth and multiplication in the gelatine-peptone medium. Thus the water collected direct from the Kent Company's well at Deptford contained—

June 4th, 1885	(temperature 12·4° C.)	6 organisms per cubic centimetre.
Oct. 29th ,,	(,, 12·0 C.)	6 ,, ,,
Nov. 25th ,,	(,, 11·7 C.)	8 ,, ,,

Again, the water from a spring in the Upper Greensand near Reigate contained—

June 5th, 1885	8 organisms per cubic centimetre
And water from a deep well in the Chalk at Sudbury, March 16th, 1886, contained	25 ,, ,, ,,

It has often been urged as an objection to the bacteriological examination of water, that such an examination fails to distinguish

between organisms which are dangerous and those which are harmless. This is, however, not the case, for there are several pathogenic or disease-producing organisms which may be readily discovered; indeed, in the case of cholera in India, this has already been done by Dr. Koch, who found the "Comma Bacillus" in a water-tank which was being used by persons suffering from cholera. The organisms of several other diseases, of which splenic fever "Bacillus anthracis" may be specially mentioned, are also capable of identification. It is only a matter of time and further investigation that other diseases shall become similarly recognizable, inasmuch as every day more precise knowledge of these forms is being acquired. The energy and enthusiasm with which this branch of study is being prosecuted is nowhere more apparent than in the Hygienic Institute of Berlin, which is directed by Dr. Koch under the auspices of the German Government. This institute has as much space and accommodation devoted to the interests of bacteriology alone as, in a Government institution in this country, would be accorded to nearly all the sciences put together.

In the application of the gelatine process to the examination of potable water, the Author points out that an opinion as to the biological purity of the water should be based not only upon the aggregate number of organisms found, but also upon the number of different varieties which the cultivation reveals. A water containing only one or two varieties is, *cæteris paribus*, to be preferred to one in which there are many varieties, as in the latter case it is evident that the water has been subject to numerous sources of contamination, and that it has not been exposed to influences inimical to the life of a number of different classes of micro-organisms. In his experiments on the artificial purification of water, he has always found that it is more difficult to remove some classes of organisms than others. The following case illustrates this point in a most striking manner. In the experiments on filtration through vegetable-charcoal it has been already seen that the—

Unfiltered water contained . . .	2,230	organisms per cubic centimetre.
Filtered " " . . .	506	" "

Reduction = 77 per cent.

If, however, only those organisms which cause liquefaction of the gelatine be taken into consideration, it is found that—

Unfiltered water contained .	785	organisms (liquid) per cubic centimetre.
Filtered " .	1	

Reduction = 99·87 per cent.

Gelatine Process applied to London Waters.—For more than a year past the Author has made periodical examinations by this process of all the waters supplied to the Metropolis, and the results obtained since September last have been officially furnished to the Local Government Board.

These examinations are of peculiar interest, when they are studied side by side with the results of similar examinations made of the river waters from which the Metropolitan supply is mainly derived. It is, of course, impossible to obtain perfectly representative samples of the water before and after treatment by the companies, but the plan adopted has been to collect samples of the river-water as it passes the companies' intakes on the same day as that on which the samples of the water actually supplied to the consumer are collected. In this manner the samples, taken over a considerable period of time, will be representative of the average quality of the river-water on the one hand, and of the actual supply on the other. A mere glance at the results of these observations, which are embodied in the following Table, will distinctly show the striking improvement, as regards the number of micro-organisms, which the river-waters undergo in passing through the companies' works. During the last four months of 1885, the average reduction in the number of micro-organisms effected by the treatment of the companies was as follows:—

1885.	Thames.	Lee (East London Co.)
September	97·8 per cent.	—
October	96·5 „	—
November	98·9 „	98·5 per cent.
December	98·5 „	88·8 „

These regular periodical examinations have already yielded some exceedingly important results.

Thus for the first time a definite conception has been obtained of the effect of sand-filtration upon these lower forms of life. Hitherto those who were acquainted with the size of these minute microscopic organisms on the one hand, and with the dimensions of the pores in a sand-filter on the other, have believed that little or no barrier could be offered to these organisms by the comparatively spacious pores of the filter, and even the strongest advocate of sand-filtration could not have reasonably anticipated that mere filtration through a few feet of this material could effect the remarkable reduction in the number of micro-organisms to which the above Table bears witness.

It is most remarkable, perhaps, that these highly satisfactory results have been obtained without any knowledge, on the part

of those who construct these filters, as to the conditions necessary for the attainment of such results. In the construction of filter-beds, waterworks-engineers have certainly never been guided by an acquaintance with the habits of micro-organisms, and yet by carefully improving their methods, so as to secure the removal of visible suspended matter, they have hardly less successfully, although unconsciously, attacked the invisible particles, and reduced them to an extent which is surprising.

The Table, however, also shows that, great as has been the intuitive wisdom of the engineers, there is still much to be learnt in the purification of water from this new point of view. A glance at the Table shows that there is a certain uniformity in the position which the various companies occupy as regards freedom from micro-organisms, and on referring to the statistics of the various companies published in Sir Francis Bolton's manual of the "London Water Supply," it is found that there is an unmistakable relationship between this position of each company and certain factors in the mode of working, which might be anticipated from theoretical considerations.

The factors which, in the Author's opinion, are more especially calculated to influence the number of micro-organisms present in the distributed water are the following:—

1. Storage capacity for unfiltered water.
2. Thickness of fine sand through which filtration is carried on.
3. Rate of filtration.
4. Renewal of filter-beds.

1. *Influence of Storage Capacity for Unfiltered Water.*—The influence which this factor may exercise upon the organized matter in water is manifold. In the first place, through greater storage-capacity, the necessity of drawing the worst water from the river is avoided, a matter which in the case of a river like the Thames, which is liable to frequent floods, is of great importance. During the period of storage, subsidence takes place, the water becoming poorer in suspended particles of all kinds. Again, in these storage-reservoirs a process of starvation may go on, for the organisms present in the impounded water find themselves imprisoned with a limited amount of sustenance, which they rapidly exhaust, and then perish in large numbers, falling to the bottom. This phenomenon is sufficiently familiar to all who have made the cultivation of micro-organisms a subject of study.

2. *Influence of thickness of Fine Sand.*—That the thickness of the filtering stratum should exercise an important influence on the number of micro-organisms passing through the filter, will be

sufficiently obvious to every one. In referring to his laboratory experiments on filtration, the Author has already pointed out that comparatively thin strata of various materials are capable of largely, and sometimes of wholly, removing the micro-organisms in the water passing through them, but that this power is gradually lost; it is only reasonable to suppose that a thicker stratum will lose this power less rapidly than a thinner one. In estimating the thickness of the filtering stratum, the fine sand only should be taken into consideration, as it is only this portion of the filter which can have any effect in the removal of micro-organisms.

3. *Influence of Rate of Filtration.*—That the removal of micro-organisms is less perfect when the rate of filtration is increased, and *vice versâ*, has been illustrated by the results obtained in the experiments already referred to.

4. *Influence of Renewal of Filter-beds.*—As already pointed out even the most perfect filtering media sooner or later lose their power of retaining micro-organisms, and hence the importance of frequent renewal is sufficiently apparent.

In considering how the differences in these various factors, which the statistics of the Water Companies exhibit, may be expected to influence the results obtained in the removal of the micro-organisms, attention must be restricted to the five companies drawing water from the Thames, as it is only these which have approximately the same raw material to deal with; for from the above Table it is seen that the amount of organic life found in the River Lee at the intake of the East London Company is very different from that in the Thames at Hampton, and the difference in the case of the New River Company is doubtless even still greater, besides the problem being there complicated by the admixture of a very considerable proportion of deep well-water.

The close proximity of the intakes of the five Thames companies, however, furnishes a favourable opportunity for instituting a comparison.

The factors in the mode of working, which have been pointed out as of special importance in exercising an influence upon the result obtained, are given in the following Table, the figures being taken from the statistical Table given in Sir F. Bolton's "London Water Supply," 1884.

MORE IMPORTANT FACTORS in MODE of TREATMENT PRACTISED by THAMES WATER COMPANIES.

Name of Company.	Average Daily Supply, in Millions of Gallons.	Available Storage Capacity, in Millions of Gallons.	Average Storage in Days (Calculated).	Rate of Filtration per Square Foot in Gallons per Hour.	Thickness of Fine Sand.	Renewal of Filter Beds (Calculated). Acreage cleaned per Month.
					Feet. Ins.	Total Acreage.
Chelsea	9·5	140·0	14·7	1·75	4 6	0·59
West Middlesex . .	12·8	117·5	9·2	1·5	3 3	0·90
Southwark . . .	19·9	66·0	3·3	1·5	3 0	0·90
Grand Junction . .	14·1	64·5	4·6	1·75	2 6	0·81
Lambeth	14·2	128·0	9·0	2·0	3 0	0·50

By means of this Table the companies may now be classified with respect to each of the four factors in question, thus:—

Company.	Storage Capacity.	Thickness of Fine Sand.	Rate of Filtration.	Renewal of Filter-beds.
Chelsea	1	1	3	4
West Middlesex	2	2	1	1
Southwark	5	3	1	1
Grand Junction	4	5	3	3
Lambeth	3	3	5	5

From this the general order of merit can be deduced, by adding these figures together for each company, and arranging them according to their average position, thus:—

Companies.	Average Position.	Order of Merit.
Chelsea	2·25	2
West Middlesex	1·5	1
Southwark	2·5	3
Grand Junction	3·75	4
Lambeth	4·0	5

From the theoretical considerations here instituted, it would be anticipated, therefore, that dealing with the same raw material, the West Middlesex Water Company should, on the whole, obtain the best average result, from a biological point of view, and that the results obtained by the other four companies would follow in the order of Chelsea, Southwark, Grand Junction, and Lambeth. On comparing this series with the number of micro-organisms

found during the last four months (September to December) of the past year, it will be seen that this series is in precise accordance with the results obtained, thus:—

	Average Number of Micro-organisms found during the four months, Sept.–Dec. 1885, in 1 cubic centimetre.
West Middlesex	6
Chelsea	15
Southwark	37
Grand Junction	64
Lambeth	70

The same series is obtained if the results are taken over the whole year, but in that case the figures for the Grand Junction and for the Southwark in March must be omitted, as on these occasions accidental contamination of these supplies had taken place, an exceptionally large number of micro-organisms being found in these months.

This coincidence between theory and practice most conclusively proves that in attempting the removal of micro-organisms from water it is no longer necessary to work in the dark, but that the problem is as tangible as the removal of those larger suspended particles which have for long past occupied attention. The only difference between the two, is that the larger suspended particles are visible to the naked eye, whilst these minute living particles require the assistance of science to render them apparent. It will also be obvious from the facts brought forward, how necessary it is that these micro-organisms should now receive careful attention, with a view to the success in practice of the improved processes indicated by scientific research. It is necessary that waterworks-engineers should become experimenters in this field, with the view of ascertaining how their processes may be carried out so as to yield the best results. It is not intended by this that they should be expected to carry out the actual bacteriological operations, for which special training is necessary, but that they should sufficiently acquaint themselves with the subject in order to carry out the necessary arrangements for such experiments on the large scale.

It must be pointed out that valuable as are the results obtained when the whole supply of each company is thus periodically submitted to examination, a much deeper insight into the working of the filters is to be obtained by the frequent examination of each individual filter-bed. The examination of the whole supply only gives a summary of the working, and the individual conditions more or less obliterate each other, but by a careful periodical

examination of each filter-bed, any defect in a detail of the process of purification would be at once detected and remedied. In fact, it is desirable that the history of each individual filter-bed should be carefully studied both for present and future guidance.

The regular biological examination of the water-supply of Berlin has now been carried out for upwards of a year under Dr. Koch, and the importance of this supervision is there duly recognized both by the State authorities and by the waterworks-engineers. England has hitherto occupied the first place in the world for the excellence of her sanitary institutions, this place she still maintains; but in future, unless practice goes more hand-in-hand with science, there is every prospect that, as already in industrial prosperity, so in sanitation, she will year by year lose ground in favour of her aspiring neighbours.

The principal conclusions to be drawn from the experiments referred to, are:—

I. That the complete removal of micro-organisms from water by filtration is unattainable without frequent renewal of the best filtering materials, and duly restricting the rate of filtration.

II. That a very great reduction in the amount of organized matter in water may be accomplished by filtering materials which have hitherto been generally regarded as almost ineffectual.

III. That organized matter is to a large extent, and sometimes to a most remarkable extent, removable from water by agitation with suitable solids in a fine state of division, but that such methods of purification are unreliable.

IV. That chemical precipitation is attended with a large reduction in the number of micro-organisms present in the water in which the precipitate is made to form and allowed to subside.

V. That if subsidence, either with agitation or after precipitation, be continued too long, the organisms first carried down may again become redistributed throughout the water.

APPENDIX.

MICRO-ORGANISMS in 1 CUBIC CENTIMETRE of METROPOLITAN WATERS.

1885.	Jan.	Feb.	Mar.	May.	June.		Sept.	Oct.	Nov.	Dec.
Thames at Hampton .	..	..	..	..	..	..	1,644	714	1,866	4,650
Chelsea	8	23	10	14	22	81	13	34	33	9
West Middlesex . .	2	16	7	3	..	26	2	2	5	15
Southwark	13	26	246	24	..	47	18	24	32	73
Grand Junction . .	382	57	28	8	21	18	43	40	40	184
Lambeth	10	5	69	30	..	38	103	26	26	124
Lee at Chingford Mill .	..	..	..	..	..	..	..	..	954	2,831
New River	7	7	95	3	..	27	3	2	11	18
East London . . .	25	39	17	121	..	22	29	53	14	317
Kent (well at Deptford)	..	..	..	..	6	..	..	6	8	5
„ (Supply) . . .	10	41	9	20	26	..	14	18	..	7

SUMMARY of FILTRATION EXPERIMENTS.

Name of Material.	Initial Efficiency.	Rate of Filtration.	Efficiency after		Rate of Filtration.	Efficiency after		Rate of Filtration.
	Reduction per cent.	Gal. per Sq. foot per hour.			Gal. per Sq. foot per hour.			Gal. per Sq. foot per hour.
Ferruginous green-sand	100	..	13 days. Reduction of	88	0·73	1 month. Reduction of	39·0	1·14
Animal charcoal .	100	..	12 days. Reduction of	100	0·46	1 month. Increase of	447·0	0·86
Iron sponge . .	100	..	12 days. Reduction of	100	0·40	1 month. Reduction of	99·8	0·45
Brick-dust (pulverized red brick .	76	..	..		..	5 weeks. Reduction of	93·0	0·48
Coke (A) . . .	100	..	..		..	5 weeks. Reduction of	98·5	0·50
„ (B) . . .	2nd day 100	0·89	3 weeks. Reduction of	85	1·32	..		..
„ (C) . . .	2nd day 100	0·67	3 weeks. Reduction of	90	1·03	..		..
Vegetable charcoal (A)	2nd day 100	..	..		..	..		..
„ „ (B)	2nd day 100	0·22	..		..	1 month. Reduction of	95·0	0·22
„ „ (C)	2nd day 100	0·26	3 weeks. Reduction of	77	0·59	..		..

[DISCUSSION.

Discussion.

Sir FREDERICK BRAMWELL, President, said the Paper dealt with a subject the importance of which was year by year more recognized, and which had received much attention resulting in a practical end. He wished to remind the members that during the last two or three sessions Papers had been read on the same subject, and many gentlemen competent to speak upon it had given their views at considerable length, and those views had been fully set forth in the Minutes of Proceedings. While therefore hoping that there would be a thorough discussion upon the Paper, he desired that, as far as possible, it should not be a mere repetition of what had already taken place and had been recorded. Sir F. Bramwell.

Dr. PERCY FRANKLAND asked permission to show the exceedingly simple process that had been devised by Dr. Koch, for determining the number of micro-organisms in water or in any other liquid. He exhibited some of the nutritive material prepared by adding a certain quantity of gelatine to rich beef-tea. It was contained in a test-tube, plugged with cotton-wool, to prevent the ingress of any aerial organisms which would in a day or two cause the gelatine to become putrid and enter into decomposition. So plugged it remained limpid for an unlimited period of time. Before being used the gelatine was melted, which he would do rapidly over a spirit-flame. In practice it was melted at a definite temperature, 30° Centigrade. It had a melting-point of about 26° Centigrade, so that it would stand the ordinary indoor temperature experienced in this country in summer. The water intended to be examined by the process was collected in a small bottle which also had been rendered perfectly free from any accidental micro-organisms by heating it in a tin-box, care being taken at the time of collection to prevent the entrance of organisms from the hand or from other accidental sources. The gelatine, it would be seen, was now perfectly liquid. The stopper was next removed from the bottle and a pipette, which had been also rendered free from organic life by heating, was introduced into the water. The cotton-wool was carefully removed, and a certain quantity of the water was introduced into the gelatine in the tube. The wool was then replaced, and the gelatine and water were mixed together. When they were thoroughly mixed they were poured upon a sterilized glass plate which rested upon another perfectly horizontal plate kept cold by means of a dish filled with iced-water placed beneath, and which caused the gelatine poured upon the upper plate Dr. P. Frankland.

Dr. P. Frankland. to set in the course of a few seconds. The gelatine was poured carefully over the surface of the plate in a rectangular form, and was covered with a bell-jar until the film was solid. When set it was put upon a horizontal stand in a dish with a glass cover over it to prevent any aerial organisms falling upon the surface of the gelatine. Into the dish was poured a little water to keep the interior in a moist state, otherwise the gelatine dried, and the organisms would not grow on the plate. In two or three days the organisms made their appearance as colonies. He would show them in a magnified form on the screen. These colonies were distinctly visible to the naked eye, and they could be readily seen and counted with the assistance of a microscope of low magnifying power. He would first show what the appearance of the plate was after it had been allowed to develop in the glass dish at a suitable temperature. Each of the large spaces shown on the screen was a colony originating from a single micro-organism introduced into the gelatine. There were different kinds of colonies, some consisting of the large spaces that were scattered about, while others were comparatively small specks, but still readily perceptible. The large colonies were those which caused liquefaction of the gelatine. The little specks on the field were colonies which did not liquefy the gelatine. The next specimen was from some water before filtration through coke, and the next was from the same water after filtration through coke. It would be seen that there were an immense number of organisms in the first specimen, and scarcely any in the second. Another plate would show the effect of agitation with coke, and another the same water after agitation and a certain subsidence. There were, as would be noticed in the first specimen, numerous liquefying organisms besides many of the colonies which did not liquefy; but in the second specimen comparatively few colonies were left. He would also exhibit a few plates with unfiltered river-water collected at Hampton, containing a large number of organisms. The next examples were from the ordinary Thames water-supply of the various companies in London, which for obvious reasons he would not specify. It would be seen that the number of organisms was enormously diminished, although a considerable number still remained in the field. Another specimen was from the unfiltered water abstracted by the East London Company at Chingford, and another example was filtered water from the Lee, where the diminution in the number of organisms was exceedingly striking. The next specimen represented the average filtered Thames water, which contained very few liquefying organisms, but still many

colonies were distributed over the field. A specimen of the Kent Company's water, as would be seen, was remarkably free, only a few colonies remaining. Dr. P. Frankland.

Mr. F. R. CONDER, having given considerable time during the last twelve months to the practical study of the theme brought forward for discussion, wished to express his concurrence in the Paper. Many persons might possibly have heard the Author speak on the same subject at the Society of Arts two years ago;[1] and they could not but be struck with the gigantic strides that had been made in the interval. He desired to confine himself within the lines laid down by their first President, Mr. Telford, and speak merely of practical investigation in that great field of inquiry. The Paper by Mr. G. H. Ogston on the subject of the purification of water by iron, and another recently read by Mr. Winter Blyth, at the Royal Society, together with some discoveries of his own, brought the whole subject into harmony. With regard to the Author's fifth conclusion, he hoped that in speaking of biological resurrection he would not lose sight of chemical resurrection. That water might be purified for a time, and then become impure, there could be no doubt. Even with the great purifier permanganate of potash, he had found that within a week or ten days there was a resurrection of turbid matter in the water, and finally an abominable putrefaction. But the great source of secondary action which interfered with all efforts in the purification of sewage was lime. The Rivers Pollution Commission had spoken of it authoritatively as a clarifier, and not as a purifier; and the secondary action which took place from the use of it was well known. At Hertford, where the sewage was remarkably weak, and where a small dose of lime, under 4 grains to the gallon, was applied, the secondary action took place some miles down the river, at Ware; the water then being of a most offensive nature, as was reported by Major Flower in 1876. The same secondary action had, he believed, been observed in almost every place where the effect of lime had been carefully watched, and most certainly where it had been mixed with iron. In the only instance of secondary action occurring in his experiments, it was due to the presence of lime and iron. At Bradford, Clifton, and Cheltenham, the same thing had occurred. In one case chloride of iron was used, and in another sulphate of iron. The secondary action was of so foul a nature that the Court of Chancery interfered by injunction, and the works were abandoned. In every case where the two sub- Mr. Conder.

[1] Journal of the Society of Arts, vol. xxxii. p. 428.

Mr. Conder. stances—lime and iron—were applied together the same result had happened.

Sir F. Bramwell. Sir FREDERICK BRAMWELL reminded Mr. Conder that the subject of the Paper was the purification of water for potable purposes, and not the purification of sewage.

Mr. Conder. Mr. CONDER said it was exceedingly difficult to draw a line. He did not wish to describe at length any process of his own, unless invited to do so by the Council; but he desired to draw attention to the samples of purified water on the table, which in two cases had been treated in the sewers themselves. There were seven points to be considered in the purification of water and sewage. The first was the destruction of odour and of gas, one of the most fatal causes of disease. The second point was the destruction of micro-organisms in the water, and there was distinct proof that iron was the only substance which absolutely destroyed those organisms. There was not a complete accordance between the experiments of Mr. Blyth and those of Mr. Ogston with sulphate of iron. That might be explained by the fact that Mr. Blyth had used an exceedingly strong solution.

Sir F. Bramwell. Sir FREDERICK BRAMWELL again called Mr. Conder's attention to the fact that the subject under discussion was the purification of water for potable purposes, and not the purification of sewage. Although Mr. Conder had stated that it was often difficult in practice to discriminate between the two, yet in a discussion there was no such difficulty.

Mr. Bischof. Mr. G. BISCHOF thought that the grain of the materials, referred to in the Paper as employed in filtration experiments, was too fine for practical purposes, and he believed that all waterworks engineers would bear him out in that opinion. He also considered that the rate of filtration with one or two exceptions was too slow to render the results practically applicable. With regard to the agitation experiments, he endorsed the Author's conclusion (p. 208) that the process was unreliable owing apparently to the numerous conditions which were necessary for its success. Considering the influence of storage on the increase of microphytes, to which he would presently refer, he contended that the samples in these experiments, which had been allowed to settle for half an hour, and for forty-eight hours, could not be compared. The redistribution of organisms referred to by the Author (p. 209), was of interest, especially with reference to biological points, but it seemed to be almost in contradiction to the statement (p. 215): "During the period of storage, subsidence takes place, the water becoming poorer in suspended particles of all kinds."

That would include micro-organisms, and he therefore did not quite see how the two statements could be reconciled. Those acquainted with the subject were aware that when water was to be examined microscopically, it was allowed to settle for twenty-four hours, when an accumulation of microphytes would be found at the bottom. The reascension probably took place only when there were currents in the water. With respect to the filtration experiments on London waters, he might mention that he had in one instance succeeded in taking a sample directly the water had left the sand filter, and he there found a reduction of 89 per cent. There was one statement in the Paper which he could not pass unchallenged: "Again, in these storage-reservoirs a process of starvation may go on, for the organisms present in the impounded water find themselves imprisoned with a limited amount of sustenance, which they rapidly exhaust, and then perish in large numbers, falling to the bottom." He would ask the Author to be good enough to reconcile that statement with the following experiment. He filled a number of glass tubes 1 inch in diameter, which had been sterilized, and drawn out at both ends to a fine point, to about one-third their capacity with water containing twenty-seven liquefying, and two hundred and ninety total colonies per cubic centimetre. The two points were immediately sealed before the blow-pipe. He kept some of the tubes (in which the organisms were certainly on starvation diet) for forty-four days, and on the last day he found that the twenty-seven liquefying colonies had increased to eighty-three, and the two hundred and ninety total colonies to one thousand seven hundred. That was the result of the starvation. There was one other point to which he felt bound to direct attention. Some time ago he was as enthusiastic as the Author himself about the gelatine test. He went to Berlin to see what was going on in Dr. Koch's laboratory, and had tried hundreds of tests, besides making a very large number of experiments with the object of testing the method itself. He asked himself what was the meaning of those colonies, and why should they be the standard of purity of water? That plain question could be answered in two ways. The colonies might behave in the same way in which chemical poisons behaved. Chemical poisons were harmless in certain quantities, and became injurious or poisonous in others. So the colonies might be harmless in certain numbers, and become poisonous in others. He was convinced, however, that that was not so, at least within a very wide limit, say within a million colonies per cubic centimetre. He would not then give the proof of it, because he could combine that proof

Mr. Bischof.

Mr. Bischof. with another point to which he would afterwards refer. The only other way that he could see of connecting the colonies with purity was, if they indicated something else which was injurious to health. That something else in his opinion could only be pollution; he therefore asked, were those colonies an indication of pollution? In order to answer that question, he might he permitted to refer to the conditions upon which the development of the colonies depended. Perhaps the most important of all those conditions was temperature, because at certain temperatures near the freezing-point, the development was entirely stopped, and then it was gradually increased in a most marvellous way, until 30° or 40° Centigrade were reached. The next point was the time allowed for development, or, as it would be called in the case of water, storage. Many of the members were probably aware of the interesting calculations made by one of the foremost bacteriological authorities—Dr. Cohn, of Breslau—some years ago, that a single bacterium would be able to fill up the whole of the ocean with its progeny in less than three days, if only a sufficiency of food, and proper temperature, were given. That brought him to the third condition, food. The fourth condition was aeration, and the last, light. It was evident that of those conditions, temperature, storage, and light had no connection whatever with pollution. Aeration certainly had such a connection, but unfortunately it was of a reverse kind, because it was well known that when there was a deficiency of oxygen, the development of microphytes was checked. Therefore, as the deficiency of oxygen coincided generally with impurity of water, so the impurity of water would actually check, as far as aeration went, the development of microphytes. Thus the only condition remaining was food. This undoubtedly was always the result of pollution, but it should be borne in mind that even in distilled water—which certainly was not polluted, in the common sense of the word, and where there was but a scanty trace of food—enormous numbers of microphytes were sometimes developed. He would go one step further. He had taken a sample of New River Water, which would have been called very good in quality by Dr. Koch, if it had contained even twice the number of colonies that he had found, namely fifty-three. He had kept the water for six days in a sterilized flask, protected against aerial infection, and then found that instead of one liquefying colony he had six hundred and forty, and instead of the total fifty-three he had seven hundred and seventy thousand colonies per cubic centimetre. If that water could by any possibility be hurtful, it surely would have

been known long since from experience, as water was frequently kept on board ship under much more unfavourable conditions, and for a much longer period. That was the proof that he had promised, that even water containing such a number of colonies was not necessarily hurtful. He would also ask this question, if in such water containing so few organisms, and generally so pure, such enormous numbers of microphytes could be developed, was it justifiable to say that no microphytes could be developed, unless there were pollution? He hoped that he should not be misunderstood. He was fully convinced of the value of the method, but it should be applied with discrimination. Above all, no attempt should be made to compare totally different waters by the numbers of colonies found. Waters which had precisely the same history might well be compared, but that meant in reality identical waters, or one and the same water, which restricted the applicability of the test. Of course there were a great many laboratory experiments, for which the test was very useful. The Author had said that it made a difference when there were different kinds of microphytes, but he could find no allusion whatever to different kinds. The numbers of total colonies only, and not even of the liquefying colonies, were given, and he presumed the Author considered that the former were sufficient; otherwise he would have added an explanation to render them sufficient. His opinion, therefore, was that sufficient advance had not yet been made to draw definite conclusions from different kinds of microphytes. The last point to be considered was, whether the search for those specific microphytes, which were the cause of zymotic diseases, such as cholera and typhoid, could be of assistance in drawing conclusions from the test. If the Author would be good enough to show him first the bacillus of cholera and of typhoid, he would search for them in samples of water. It was true that Dr. Koch was of opinion that the Comma Bacillus was the cause of cholera, but as long as bacteriologists and pathologists could not agree upon the point, he as a chemist could not be expected to pronounce an opinion upon it. He hoped, therefore, that the Author would be good enough to explain thoroughly why he believed that those colonies had any necessary connection with wholesomeness. Mr. Bischof.

Mr. JABEZ HOGG remarked that the purification of water in its many-sidedness had been pretty freely thrashed out on former occasions. However, a very important change had taken place. It was now admitted by the analytical chemist that henceforth water purification must rest on a twofold basis—biological and Mr. Hogg.

Mr. Hogg. chemical. In the earlier attempts at purification, water-engineers, and he thought he might say all classes of the community, were content if by filtration all visibly suspended matters were removed. If the water after passing through a filter-bed had a bright, clear appearance, it was said to be a good and wholesome water. More recent investigations, however, had demonstrated the fallacy of this view, and in point of fact it was now well known that the brightest and clearest-looking water might contain a deadly organism—a micro-organism, of course—invisible to the unassisted eye, and undiscoverable by chemical analysis. With the advance of the germ theory of disease the necessity for a test, which should recognize the absence or presence of these micro-organisms, became an imperative one, and it was but right to say that the credit of the discovery of a reliable test—the biological—was due to a member of the medical profession, Dr. Koch of Berlin. This test he had the honour of introducing to the notice of the members of this Institution four years ago,[1] and at the same time he exhibited photographs of the results of his examinations of London water, as well as of Manchester water, which the late Dr. Angus Smith was engaged upon. Since then he was glad to find the Author of the Paper had been diligently at work with Koch's test, both in his laboratory and "in his periodical examinations of the waters supplied to the metropolis." He now submitted for acceptance the general conclusions to which he had been led by his experimental researches in water purification. Mr. Hogg's remarks would be chiefly confined to the biological part of the question. He thought it would be not only convenient, but absolutely necessary, to get a clear insight into the nature of these exceedingly minute organisms before venturing upon or attempting to deal with the more difficult part of the question, their separation from water, by filtration or other process. It must not be supposed that the micro-organisms in question bore any resemblance to those larger organisms which infested water, many of which could be seen by the unaided eye, as entomostraca, pulex, &c. No idea either of the excessively minute bodies known as bacteria, microbes, &c., would be gained from the magnified pictures which had been thrown on the screen. It could hardly be imagined that those irregular masses, those colonies, consisted of hundreds of millions of living micro-organisms. To describe them individually, or rather to speak of them collectively, and as a genus, they measured from the $\frac{1}{5,000}$ to the $\frac{1}{50,000}$ of an inch, their movements

[1] Minutes of Proceedings Inst. C.E. vol. lxviii. p. 92.

being regulated by a motor fibre, a flagellum, placed at the extremity of their bodies, and which measured only the $\frac{1}{200,000,000}$ of an inch. Their outer covering or skin was chiefly composed of cellulose, which enabled them to resist the action of strong acids and alkalies, as well as the variations of temperature, cold and heat. As an example of the former he had repeatedly placed them in strong fuming nitric-acid, and at the end of a week or a month had seen them as lively and apparently as unaffected as they were in their natural element. Life was even more persistent in the germs, spores, or ova, than in adults, and it would be an act of rashness to say when every individual of a colony had been entirely destroyed. If the water in which micro-organisms lived was much agitated, or the supply of food fell short, the colony would invest itself with a gelatinous matrix, and sink to the bottom of the water. Germs, or resting spores, would remain quiescent and concealed for a lengthened period of time. Light was an essential for the development of some species; darkness for others. A free supply of oxygen was required by some, others lived and throve without it. But all must have carbon and nitrogen, and these elements they freely obtained from the organic compounds held in solution or suspension in most waters, especially those polluted by sewage. Micro-organisms pervaded air, earth, and water; indeed were so very ubiquitous, that water seemingly free from them at one period of the day might swarm with them later on. There were very many varieties or species of micro-organisms, bacteria, some of which were believed to be harmless, whilst others were known to be poisonous, pathogenic, or incitative of zymotic disease. From this rapid sketch of their natural history it might be inferred that all attempts at sifting them out, or straining them off, from their natural element, water, must be attended with very unusual difficulties—often entire disappointment. To say that this could be done by filtration was, he thought, scarcely warranted by the results already obtained. At all events the experiments he had made with the view of water-purification had not been attended with much success. He was then unable to accept the general conclusions which the Author had arrived at. He did not doubt that filtration would considerably improve water; but any process, were it filtration, precipitation, or what not, and which merely reduced organic life to a minimum, went only a short way towards water-purification. The one or two colonies, or even the one or two individuals, which any process left behind, was a danger which could not be contemplated without producing a shudder. The difficulty

Mr. Hogg.

Mr. Hogg. must have been present to the Author's mind when he said (p. 199) that "the microscopic living particles . . . possess such an astonishing power of rapid multiplication . . . that within a very short period of time it becomes impossible to form an opinion as to the number of original organisms from which the vast population is descended." Just so; and it was therefore the more surprising he should believe it to be "extremely simple to construct filters which shall possess the power of removing micro-organisms, in the first instance at least." Speaking from a not inconsiderable experience, he had not seen or heard of a filter-bed which might be trusted to remove two-thirds of the coarser and larger organisms so generally met with in London waters during the summer months of the year. It appeared then almost impossible that a water-logged filter, or even a new filter-bed, should remove 90 per cent. of micro-organisms so infinitely minute, and so much more difficult to deal with. How very much, then, was the Author's warning needed to guard against erroneous and hasty conclusions that even the best filters soon lost their power, and consequently must be frequently renewed. There was still, he was convinced, much to learn with regard to filters and filtering materials, and this came out more strikingly on examining them in detail. Take either filtration, precipitation, agitation, or natural agencies, and none of them effected the perfect purification of water. Partial failure was the rule. The spongy-iron process, by way of example, at the Antwerp Waterworks. It was only two or three sessions ago that this was spoken of as a great success. Where was it now? Displaced by "agitation with solid particles." The same fate had been in store for many other processes. He knew of only one exception to the rule—Clark's lime process. This more nearly approached perfection than any other, and possibly its greater success might, in a measure, be due to the excellence of the water in the first instance, for it could not be denied that deep well-water was the best, and least likely to be contaminated, of any of the waters supplied to London. If examined biologically and microscopically soon after precipitation was completed, it would be found free from organisms of all kinds. Indeed, he had submitted it to a further test, that of keeping the Canterbury water bottled up and exposed to a strong light, and a uniformly higher temperature in his study, for a whole year; and then, on testing it biologically, he found it free from all micro-organisms. This, then, to his mind, was the water, and the water process of the future. The Author further alluded (p. 213) to the difficulty he experienced in the removal of some classes of organisms over others.

This was a difficulty experienced by many observers. He also appeared to have a preference for the gelatine-peptine solid medium over that of other modes of cultivation. Mr. Hogg found it necessary to employ occasionally less solid media, and for the reason that certain micro-organisms preferred them, and multiplied more rapidly in them. Among solid media he had a preference for the agar-agar and peptone sugar culture. He would remind the Author that particular species would only propagate in a medium containing less than 10 per cent. of gelatine. Again, septic microbes remained in a quiescent state in the presence of commoner forms, possibly enemies. There were other points of detail and precautions to be observed, which, if neglected, marred the results of experiments, and gave rise to erroneous conclusions. Some error of observation had, he was inclined to think, been the cause of a misunderstanding with regard to Dr. Koch's cholera bacillus. There was a Comma Bacillus, of a somewhat harmless character, often met with in the human mouth, and in other situations. This was a very different organism. Dr. Koch's bacillus had a certain selective preference for one kind of gelatine cultivation over that of another. Dr. Crookshank, who had bestowed a good deal of attention upon micro-organisms, said of Koch's: "No one, so far as I am aware, has yet been able to demonstrate the existence of a curved bacillus which is entirely similar, both morphologically and biologically, to the (cholera) Comma Bacillus of Koch." The Author of the Paper would, he feared, think him either very fastidious or very difficult to please with regard to water-purification. It was so, he must admit; and this arose from the fact that the longer he studied the question the more difficult it became to reconcile differences of opinion which experimental researches almost invariably gave rise to, in the first instance at least. Mr. Hogg.

Mr. S. C. Homersham said that the Author had compared the Thames water supplied by different London Companies one with the other, and had stated that the West Middlesex was the first in order of merit. If, however, water was drawn from a main-pipe, say in the Strand, it would be found to be in a very different condition, biologically, from that of water collected at the "dead ends" of service-pipes branching from the main down a street bounded by the river. Near to these dead ends, where the water was not in motion, organisms lived and bred, and were to be found in swarms. In the mains, where the water was in motion, there were but few, and more especially where there was a comparatively quick current. It was essential, even with the best water, that the dead ends should periodically—at intervals of not Mr. Homersham.

Mr. Homersham. more than seven to fourteen days—be blown out. The water at these dead ends would be found somewhat thick and muddy, and containing thousands of animalcules. It was delusive, therefore, to compare the water of different companies unless it was known exactly where the waters were taken from, the time of the year they were collected, and other conditions. The number and the species (animal and vegetable) of the living organisms varied greatly in different situations and at different seasons.

Mr. Anderson. Mr. W. Anderson (Erith) thought that the Paper should be accepted as a useful instalment to knowledge on the important question with which it dealt, although he could not himself agree with the conclusions to which the Author had arrived, and considered that there were some fatal defects in the arguments he had adduced. In the first place, it had not been proved that the gelatine method of investigation arrested all the microbes, or even the more objectionable ones. In fact, experience rather tended to show the contrary. Last autumn a commission of chemists was appointed by the Hôtel de Ville of Antwerp to examine into the quality of the water-supply of that city, for the town was crowded with visitors attracted by the Exhibition, and there was a considerable cholera scare caused by the prevalence of the disease in Spain. The result of that examination was a report (a copy of which would be found in the Library) in which it was stated that the water was absolutely sterile to Dr. Koch's test. No bacteria of any kind could be found by the cultivation in gelatine, but by cultivation on slices of potato abundant life was discovered. That showed that the method of Dr. Koch was defective, because it did not necessarily embrace all the life that might be found in the water, and that the conclusions derived from it were therefore fallacious. Then it had not been proved that the indiscriminate destruction of bacteria was an advantageous thing. He supposed that it might be taken for granted that the destruction of some species would be an advantage, but it was a great question whether the wholesale destruction of living organisms in impure water would be beneficial. In olden days, when sailing ships made long voyages, the kind of water preferred was the dirty water of the London dock, because it was found that, although, at first, it was extremely offensive, it gradually cleared, and then kept better than any other kind. That was no doubt due to the fact that the living organisms first of all destroyed the organic matter which was in the water, and by that very destruction destroyed themselves and settled down as sediment on the bottom, leaving the water quite clear, and in a condition to keep any

length of time. In that case the living organisms were clearly of great benefit, and it had yet to be proved that it was wise to destroy them. Just as small birds preyed upon insects, and so did more good than they did mischief, it was quite conceivable that some harmless species of microbes preyed upon the injurious species, and it was by that means that water which had been contaminated by the germs of zymotic disease gradually cleared itself and became inoffensive again. He also took exception to the tests by which the Author sought to determine the relative efficiency of various filtering media. He thought it would be only reasonable, first of all, to ascertain what was the best state of sub-division, the best depth, the best rate of filtration of any particular medium, and then, having ascertained that, to institute a comparison between the media when working at their best. Instead of proceeding in this manner, however, they had all been taken at the same fineness, the same depth, and approximately at the same rate of flow; or at any rate, if the flow had been varied it appeared to have been so accidentally. He did not think it was fair to assume that all the substances tried would act equally well under the same circumstances; and in that respect he thought the argument about the relative efficiency of filtering media was erroneous. As far as iron was concerned he could speak with some authority, because he knew by experience that iron passed through a forty-mesh sieve, and arranged in a layer 6 inches deep, would, in three months, be altogether impervious to water. Iron could not be used as a filtering medium in that way. Mr. Jabez Hogg's statement that the process originally adopted at the Antwerp Waterworks was a failure, was altogether incorrect and misleading. Mr. Bischof's system of passing water through a mixture of gravel and iron was perfectly efficient, and continued to be so for more than three years; but, in the mean time, a method was discovered of attaining the same object by agitation with iron; it proved to be more economical in working, and to require much less space and capital outlay, and was, on those accounts, adopted when the works had to be extended. He also took exception to the Author's conclusion III., "That organized matter is to a large extent, and sometimes to a most remarkable extent, removable from water by agitation with suitable solids in a fine state of division, but that such methods of purification are unreliable." He supposed that the Author did not intend to include iron in that statement, because, although iron was used by agitation, the effect it produced upon water did not depend upon any mechanical action, Mr. Anderson.

Mr. Anderson. but upon a chemical process; and that it was absolutely permanent was proved by the fact that it had been purifying from 1,500,000 to 2,000,000 gallons of water daily, at Antwerp, for more than a year, and, as far as he could see, there had not been the smallest variation in the results. Whether the Author's conclusions held good with reference to gravel, brick-bats, and similar inert substances, he was not prepared to say—probably it did; but certainly he thought the Author ought to make an exception in favour of iron. He did not think that any one process of treatment was competent, of itself, to deal with impure water; but he was certain that, by taking three out of the four systems to which the Author had alluded, it was possible to obtain from water, however impure, not only a perfectly safe, agreeable, colourless, potable fluid, but one which, he believed, was much safer than any natural supply, not excluding even that of deep wells. He had repeatedly shown, both from a biological and from a chemical point of view, that by treatment with iron, a process discovered more than thirty years ago by Medlock, and further developed by Mr. Bischof and Sir Frederick Abel, that a chemical change was produced, and the organic impurities were reduced to one-third or one-fourth, that the microbes were either destroyed or entangled in the precipitate, and separated by sand-filtration; the colour and the bad taste were also destroyed, and water of a thoroughly good quality was produced, not by one process, but by agitation, chemical action, precipitation, and filtration. When that had been done, the water was put into covered reservoirs or mains, which were absolutely free from risk of external contamination; and he considered that such water was better than any natural supply. The process sounded formidable and complicated, but in reality it was merely ordinary sand-filtration with the Revolving Iron Purifier added. The expense of purification was not materially increased, for the cost of the water at Antwerp delivered into the main under 200-feet pressure did not exceed 7*d.* per 1,000 gallons, interest on capital not included. All rivers or lakes, however pure, were liable to contamination, and deep wells were by no means free from the danger, for there had been numerous instances in which wells, in the neighbourhood of London anb other places, had been closed in consequence of the contaminations produced by increased population. The process, therefore, which embraced not one only, but several methods of purification, was capable of producing excellent water from sources which had been hitherto considered unsuitable. He might also speak of the universality of its application; because, although the Antwerp Waterworks had been

prominently put forward, that was by no means the only case in which the method had been tried. He had employed it with the waters of the Neva and of the Nile, the sluggish rivers of Holland and Belgium, with the waters of the Seine, and even with the effluent of the Hertford sewage works, with thoroughly satisfactory results. Wherever it had been tried, the result had been the same: the reduction of organic matter to one-third or one-fourth, the destruction of colour, of the objectionable taste, and a renewal of organic life. He thought that all would agree that the destruction of chemical impurity was a very important feature, because the microbes could not exist without the nitrogenous substances which formed the organic impurity, and which hitherto had been rightly regarded as of very great importance. Therefore any process which would not only destroy the microbes, but which would also destroy the food upon which they existed, must be a valuable one. He took exception to the Paper, because it had a tendency to produce an impression, upon those not well acquainted with the subject, that the power of a filtering medium to destroy living organisms was the great thing to be considered, and was the proper test of efficiency. He did not think it was. He believed that all the circumstances connected with a good water-supply must be taken into account. The engineer who neglected the colour and taste of water would find that if he had to supply a town in which there was spring or well-water of agreeable taste, colour, and brightness, even though greatly polluted, that a water company would have a very uphill game if it supplied a yellowish, ill-tasting liquid. Mr. Anderson.

Mr. JAMES MANSERGH said the subject was one of great interest to engineers, especially to those engaged in the construction of waterworks. It was a very fitting subject for consideration by the Institution, although, as it was a new development, few of the members might be able to enter into a close discussion of its details. He himself certainly was not. They could not afford, however, to ignore the researches of the chemist, the biologist, and the physiologist, and their thanks were due to the Author for the graphic manner in which he had brought forward the results of his experiments. He had had the advantage of being a pupil of his father's several years before the Author was born. If he might be allowed, without impropriety, to make a purely personal reference, he should like to state that he had a further special interest in the subject, because he had been for some time experimenting, under the advice of an American physician, on a treatment which had involved the taking of a large quantity of Mr. Mansergh.

Mr. Mansergh. undiluted hot water daily. To such an extent had that been the case that, taking the basis of the figures which had been given as to the number of microphytes found in the filtered water of certain of the London companies, he found that his share during the last eighteen months had been 23,198,400 individuals, possibly colonies—he hardly knew which. He thought it was clear from that experience that the great majority of these organisms were clearly non-pathogenic, that was, inoperative in the production of disease under ordinary conditions. On the other hand, it was equally certain, from the labours of Pasteur, Dr. Koch, and others, that there did exist organisms which undoubtedly possessed truly pathogenic capabilities. For that reason it was of the utmost importance that biological researches should be prosecuted with vigour, especially in the direction of determining which organisms were dangerous, and which were innocuous. In this country scientific men were, he feared, handicapped by the operations of the Anti-Vivisection Acts—backed up in certain quarters by false and mischievous sentiment—and were unable to carry out their researches to the extent permissible on the Continent. This was very unfortunate, because it was absolutely necessary in such inquiries as Pasteur's to make good each step as it was taken by actual experiment upon some of the lower forms of animal life. He would ask the Author, in his reply, to give a little further explanation of the blister-like appearance of several of the plates. He had to some extent explained it by saying that certain of the organisms had the power of liquefying the gelatine, but he thought that that might lead to considerable errors in the counting of the numbers. Surely those great blebs must spread over and obliterate many of the small compact colonies which were shown on the diagrams. He would also ask for the Author's opinion upon the discoveries of Mr. R. Warington.[1] Mr. Warington had found that there were certain bacteria which effected the nitrification of other organic matter, and that these creatures had their habitat in the upper surface of the soils of manured lands. Those experiments were carried out on the model farm at Rothamsted under Messrs. Lawes and Gilbert. Mr. Warington appeared to have satisfied himself that the nitrification was due principally, if not entirely, to these microbes. If these conclusions were correct, it would appear that the Author's suggestion, to drain the beds of the intermittent filtration process for the purification of sewage which he had invented, 6 feet deep, might be materially modified.

[1] Journal of the Chemical Society, vol. xlv. 1884. Transactions, p. 637.

Impressed with this idea he had some months ago discussed the matter with Dr. Frankland, and had subsequently advised the preparation of four burnt clay filtration areas on a sewage farm near London, side by side and of exactly similar size and formation, excepting that the depths were respectively 2 feet, 3 feet 3 inches, 4 feet 6 inches, and 6 feet. These were now being experimented with, and the results would be interesting as proving or disproving that the shallow beds were as efficient as the deeper.[1] He was also considering the advisability of importing soil from a farm where the nitrification went on satisfactorily, and sowing it, with its contained bacteria, upon another apparently deficient in those organisms, so as to inoculate the latter into efficiency. Coming back directly to the subject of the Paper, it appeared to be clear that the microbes in the case of the sewage-farm were performing an exceedingly useful function; and he should like to ask the Author if it might not be that the majority of the organisms found in potable waters were operating in a similarly beneficent manner. Mr. Mansergh.

Mr. E. K. BURSTAL remarked that the Paper was of a purely chemical nature, and that it was somewhat difficult for engineers to grasp its details fully. The tables certainly showed the wonderful effect produced upon water by mere sand-filtration. Only 2 or 3 per cent. of the microphytes remained, but it was not evident whether it was the dangerous ones that had been removed. The healthy condition of London would seem to indicate that that was the case. He certainly took exception to the way in which the "order of merit" had been obtained. In the Table at the top of p. 217 there were six columns. In the third column the average storage in days began at 14·7, and therefore the Chelsea Company, having that figure, was credited with the first place. The numbers 1, 2, 3, 4, 5, &c., were purely arbitrary, and ought to be accepted with great caution. The rate of filtration per square foot was the same. Regarding the thickness of sand, there was nothing to show that 4 feet 6 inches was better than 3 feet 3 inches. As to the average number of micro-organisms found in the water, the number for West Middlesex was six, and for Chelsea Mr. Burstal.

[1] It was a curious coincidence that on the 14th of April, the day after the above remarks were made, a letter appeared in *The Times*, written by Dr. E. Frankland from Castellamare, referring to a report on the mode of treatment intended to be adopted by the Metropolitan Board of Works for the London sewage, and stating that whereas in the Rivers Pollution Report he had recommended 6 feet depth of earth for intermittent filtration, he now had reason to believe that 2 feet would be equally effective.

Mr. Burstal. fifteen, but the Author stated that the number in water from a deep well in chalk at Sudbury was twenty-five. After all that had been stated by the Author's father and himself, and all the attacks that had been made upon London water, did he mean to imply that sand-filtration rendered the water better and more potable than that obtained from the chalk? If that was the case the new method of examining water would lead to a thorough revolution in the views generally held on the subject. He did not think that a stronger argument in favour of the quality of the water at present supplied to London could be found than that contained in the Paper, if the facts stated were correct. Mr. Anderson, however, appeared to think that the gelatine process ought not to be accepted in all respects as a satisfactory one. It would be interesting to know what were the views of chemists on the subject. As he before stated, he could not agree with the order of merit given by the Author in regard to the quality of the waters.

Mr. Beaumont. Mr. W. W. Beaumont said that although some of the criticisms on the Paper had been adverse to the use of the system described, there had not been for a long time before the Institution a Paper that was so flattering to engineers in the results which it related. The figures in the Paper showed that the Thames water, notwithstanding the character often attributed to it, might be as good as that which was most praised by chemists. The system described had been, it was said, brought to perfection by one who had more laboratory room and materials at his disposal than could be found in the whole of England, and it might therefore be assumed that the figures might be taken as of as much value to engineers as anything the system with its numerous sources of vitiation could give, in enabling an opinion to be formed as to the results of engineers' work. It appeared from the Tables that the Kent well-water as supplied contained many more micro-organisms than the Thames water supplied by the West Middlesex Company. The water from the Kent wells at Deptford contained from six to eight micro-organisms, but as supplied it contained as many as twenty-six. If the water from the well to the supply could so gain in pollution it was somewhat remarkable that there was so small a growth of organisms in the water supplied by the river companies, because it must be assumed that the water was purer, as far as the organisms were concerned, in proportion to the numbers in the water as it left the filters in the one case and the wells in the other. That did not, however, seem to be the case, for, taking some of the other figures, in the Grand Junction and Chelsea

Works the numbers remained very low, and the Author had pointed out that those numbers bore some direct relation to the thickness of the filters or of the sand-beds—in other words to the amount of mechanical action to which the water was subjected. The Paper was gratifying to engineers, because it showed that they had for a long time been able to do, with the means at their disposal, as much as chemists and biologists could now teach them to do by their most recent researches, aided by the most complete apparatus. The Author, in describing his process, stated that in taking the gelatine from the bottle it was necessary to be very quick in putting it under the glass vessel. If, however, the result of a test could be vitiated by so short an exposure, it was not surprising that the Kent water was found to rise suddenly in impurity from six or eight organisms to twenty-six, as between the well and the Company's pipes. That proved that, although the water supplied by the river companies was so good, it would be even better if it could be a constant supply. If the water could be rendered so rapidly impure as the Author's remarks appeared to indicate, London people must, as a rule, be drinking water from the ordinary house cisterns that was vitiated largely by organisms. Mr. Beaumont.

Mr. W. Morris (Deptford) said he thought the Paper most interesting to engineers, as it showed what filter-beds were really doing. He believed that some of the organisms referred to would be found in the waters of all lakes and rivers. After passing through filter-beds there was, as the Author had shown, a very great reduction in the number of the organisms, but it would appear that those which remained in the filtered water increased so rapidly that if the water were kept long enough it would be found to contain its original proportion of colonies. If the organisms contained in good potable waters had no influence on health, their number would be of little importance; but, as had been urged by chemists and other scientists, such water might be accidentally contaminated by disease germs or pathogenic organisms derived from excrement or other sources, and to provide against such a contingency it became important to remove the whole of the organisms by filtration, although only a very small percentage might be really injurious. If the present system of filtration had in some cases removed 98·9 per cent. of the organisms, was there not reason to believe that by improved filters even better results might be obtained? The results given by Mr. Anderson of agitation with iron pointed to another valuable means of purifying water in connection with filtration. The depth of the sand used in filter-beds had been alluded to, but Mr. Morris.

Mr. Morris. the quality of the sand was also a matter of some importance. There might be a great depth of sand, but if it were not sufficiently fine the result would not be so good as with a smaller depth of a finer and better material. From his experience of the filter-beds formerly in use at the Kent Waterworks, he believed that the deposit of suspended matter, and the growth of vegetation on the surface of the sand, materially assisted in the filtration of the water; as it had to pass through the interstices of much finer strainers than the sand itself. In Berlin it was reported that covered filter-beds were not so efficient in removing these organisms as those which were open and uncovered; the reason for this might be that the covering of the filter-beds checked the growth of the vegetation on the surface of the sand, which would have assisted in the removal of the organisms.

Mr. Folkard. Mr. C. W. FOLKARD thought that one or two of the speakers had hardly been fair in their criticisms, because the first thing a scientific man ought to do was to follow the truth, and if it was necessary, in some little way, to go back from his opinions, that ought to be done. Four years ago he read a Paper on a somewhat similar subject before the Institution,[1] and he thought that since that time very great strides had been made in the examination of water. He was then strongly of opinion, as he believed most people were, that there was no method by which to determine whether water was wholesome or not. Of course Dr. Koch's method was not perfect, but he thought chemists were now on the road to a process which would show whether water was really wholesome as distinguished from being chemically pure. As a pupil of the late Dr. Medlock, he thanked Mr. Anderson for pointing out that to the former was due the credit of first drawing attention to the great power of iron in purifying water.

Mr. Ekin. Mr. C. EKIN remarked that one point in the discussion had not been sufficiently elucidated. Mr. Anderson, in alluding to the fermenting process that took place in the case of Thames water taken on board ship in the olden times, and its subsequent wholesomeness, hinted at the possibility of micro-organisms in water being somewhat beneficial in their operation. As a matter of fact, he believed that they were among their best benefactors, for what Mr. Anderson had supposed might take place had actually been proved to do so. In a discussion at the Chemical Society a few weeks ago Dr. Klein,[2] who was an authority perhaps hardly

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[1] Minutes of Proceedings Inst. C.E. vol. lxviii. p. 57.
[2] Journal of the Chemical Society, vol. xlix. 1886. Transactions, p. 201.

second to Dr. Koch, assured the meeting that the septic organisms were absolutely inimical to the pathogenic organisms that accompanied disease, and not only were they inimical, but they were so much stronger, and their vitality so much greater, that it was not possible for the disease organisms to exist in their presence. With the caution and diffidence of the true man of science, Dr. Klein confessed that there was much that was hazy in the present knowledge of these organisms, and he especially warned chemists against drawing deductions from very incomplete data. The fact of the one set of organisms destroying the other was, however, clear, and its practical importance could hardly be overrated. It explained, too, that which had hitherto been a mystery. Many present must have often marvelled at the fairly good health of communities drinking waters even grossly polluted. The Thames received quite sufficient pollution, but it was purity itself as compared with several of the rivers supplying some of the northern towns. Now these rivers received the dejecta of thousands of patients suffering from typhoid fever, and it was a wonder what possible agency could be at work to prevent the wholesale decimation of the populations subject to these influences. Wherever pollution existed, bacteria swarmed, apparently in some direct ratio to the extent of the pollution. If their presence was fatal to the existence of the organisms accompanying disease, and Mr. Ekin had spoken and written of them for years as playing the part of useful scavengers, then instead of holding them up to opprobrium, they ought to be looked upon as real benefactors. It must not be supposed, however, that he advocated swallowing the scavenger, or that he undervalued efficient filtration. He only wished to caution the meeting against sensational deductions from the presence of the few bacteria that might be found in filtered river waters. Mr. Ekin.

Mr. J. A. WANKLYN said that the subject of the Paper was one in which he had been interested for nearly twenty years, and he believed that his views were pretty well known through the medium of his book. His belief was that there was one safe and rational way in which to regard organic matter in drinking water, and that was to assume that it was highly dangerous, and to classify waters according to the proportion of organic matter present. He attached very little importance to searching after organisms in drinking water; indeed he looked upon such investigations with a great deal of contempt. Eighteen years ago, before the Royal Commission, presided over by the Duke of Richmond, he ventured to say that the London water was cleaner and more wholesome than the water of Loch Katrine. He was laughed Mr. Wanklyn.

Mr. Wanklyn. at at the time, but now even Dr. Frankland, who at that time talked of mountain air and mountain water, had come to admit that there was more organic matter in Loch Katrine than in certain London waters. With regard to the question of filtration, he held that organic matter could be removed from water with the greatest ease by filtration through many media.

Mr. Homersham. Mr. S. C. Homersham observed that the statements which had been made with regard to taking in water from the Thames for vessels in the docks near London, that it fermented on the voyage, and afterwards became clear and good, were entirely erroneous. He had, many years ago, closely investigated the matter, and was therefore able to speak with confidence on the subject. Mr. Martin, the Engineer to the West India Docks Company, had informed him that many years since the Company went to the trouble and expense of putting up filter-beds to filter the water obtained for this purpose from the Thames; that it was, however, found to become so bad on the voyage that the Company gave up using it, and resorted to other water. This had been the case for many years past. Many vessels now obtained supplies of uncontaminated spring-water derived from the chalk at Erith, Gravesend, and other suitable places alongside the Thames.

Dr. P. Frankland. Dr. Percy Frankland, in reply, said he had been asked to explain more fully than he had already done, some of the details of the process of gelatine culture. In the first place the gelatine and peptone mixture did not develop organisms of itself, but they had to be imported into it either from the air or from water or from some other external source; and then the question had been asked how it was possible to separate the organisms introduced from the water from those introduced from the air during the manipulations which the process entailed. Into the first of those questions it was hardly necessary to enter. Of course it involved the well-known question of the spontaneous generation of life. It had long been fully established that if the media which were capable of nourishing those lower forms of life were sterile, and were then preserved from the access of such low forms of life or their germs, they would remain unchanged for an indefinite period of time. Every pot of jam and tin of meat was an illustration of that principle. The jam or meat was sterilized, and as long as the pot which contained it was not open it remained unchanged: but as soon as aerial organisms gained access various putrefactive and other changes would in time take place. The introduction of organisms from the air probably required more explanation. It was, no doubt, observed that, in his manipulation, the greatest care was taken that the exposure of the plate

Dr. P. Frankland.

to the air should be as short as possible; but even with such exposure there was, at any rate, a risk, especially in a room where there was a good deal of dust, of considerable contamination taking place. In all cases when plates of that kind were put up for examining waters or other liquids, he made a practice of putting up at the same time a plate to which no water had been added, but which had experienced the same exposure to the air as the water-plate. Then if the plate showed any serious aerial contamination, he should expect to find the same in the water-plate, and the experiment would be rejected. To show that under ordinary circumstances that was not the case, he had brought with him a few plates to exhibit to the members. There was an air-plate containing absolutely no organism upon it, and there were two plates with the cultivation of a Comma Bacillus. If the air had not been as pure as it was on the occasion when the plate was put up, two or three organisms might be found; but in comparison with the ordinary plates that slight experimental error was of very little moment. These aerial organisms could generally be readily distinguished from the organisms derived from the water, because they rested absolutely on the surface, and they were generally moulds, while the organisms found in the water were very rarely moulds. He much regretted that several of the speakers, and notably Mr. Bischof, had imported much into the discussion which had really no relevance to the matter contained in the Paper. Mr. Bischof had started with the assumption, and many other speakers had done the same, that he had endeavoured to make out a case for the existence of a connection between the abundance of micro-organisms in water and its wholesomeness. That assumption had been made without reference to any particular passage in the Paper, and he thought that Mr. Bischof and the other speakers would find some difficulty in pointing out any passage, either in this Paper or in any of his previous publications on the subject, in which such a connection was said to exist. He thought that Mr. Bischof had confounded his own previous attitude of mind with Dr. Frankland's, and it was really against himself and his own utterances that his attack should have been directed. From the first, Dr. Frankland's idea had been to apply the gelatine process to an investigation of the much-vexed question of the value of processes of water purification, which had hitherto rested upon an altogether speculative basis. It was with that view that the experiments he had brought before the Institution were undertaken; it had been with that view that

Dr. P. Frankland. month by month the London waters had been submitted to examination by that test, and a little consideration would at once render it apparent that that investigation could be carried out without any reference to the influence of those micro-organisms upon health, the problem being simply to ascertain whether and to what extent various processes of purification had the power of removing micro-organisms in general; but the results obtained in such an investigation, made as it had been with the motley assemblage of organisms found in unfiltered river water, in soil extract, or in sewage, obviously had a wider significance, inasmuch as those processes of purification, which were capable of removing such a heterogeneous crowd of microbes, might be safely assumed to be able to deal with any other kind of micro-organisms whatever, whether harmless or pathogenic, because neither in their size, nor in their form nor in their habits, could pathogenic organisms be sharply distinguished from non-pathogenic. Thus, in the matter of filtration, there was absolutely no reason to suppose that a pathogenic organism behaved differently from a non-pathogenic organism. He emphatically stated, and he challenged contradiction, that he had never gone beyond that in his conclusions. He had never asserted that water containing a smaller number of micro-organisms was *ipso facto* more pure or wholesome than another water containing more. His Paper treated of the removal of micro-organisms in water, and not of the wholesomeness or unwholesomeness of such organisms in general. On the point of removing micro-organisms from water, of which so much used to be said by Mr. Bischof before any satisfactory means of determining such removal was in existence, Mr. Bischof was now ominously silent. In that lay, doubtless, a key to his acknowledged loss of enthusiasm for the process. He had listened with much interest to the remarks of Mr. Jabez Hogg, concerning the behaviour of the organisms; but he was not prepared to endorse the statement that micro-organisms might be preserved in fuming nitric-acid without suffering any discomfort. He had not the slightest doubt that when the micro-organisms were placed under the microscope, they still showed movement; but he ventured to say that if they had been submitted to cultivation in gelatine, or some other nutritive medium, it would have been found that their vitality was lost. Those minute organisms, in common with other minute particles, exhibited a peculiar kind of motion which had nothing to do with vitality. A number of similar experiments showing the extraordinary powers of resistance which micro-organisms were supposed to possess, had been placed before the

Chemical Society some years ago by the late Mr. J. Hatton,[1] who applied no further test to the organisms beyond looking at them under the microscope and seeing them move about. Those tests were, of course, made before the test of gelatine cultivation, though not before the ordinary broth cultivation, and he thought it was high time that the fallacy of that mode of recognizing the vitality of micro-organisms should be pointed out. Mr. Homersham had stated that it was impossible to compare the various water-supplies, inasmuch as the samples might be taken from the dead-ends of service-pipes branching from the main. All the samples to which he had referred had been taken from places which were expressly recommended by the engineers of each individual company, and he need hardly say that he did not think these gentlemen would recommend the taking of samples from such manifestly unsuitable and disadvantageous places. Of course, if samples were taken from such places the results would be very different. With regard to Mr. Anderson's criticism of the gelatine process in general, and the illustration which he gave of its alleged weakness by referring to the results obtained in Antwerp, he could only say that he could not be responsible for other people's gelatine. He had no doubt that some gelatine, improperly prepared, might not develop organisms at all. Much depended upon how the gelatine was made. He knew the quality of the gelatine which he himself made, but could not be prepared to guarantee the results obtained from gelatine made by anybody else. The mixture to which he had referred was used by Dr. Klein in this country, and by nearly every bacteriologist engaged in the cultivation of micro-organisms. It was quite true that the gelatine-peptone medium was not suitable for the cultivation of all micro-organisms, but it was well adapted for the vast majority of known forms. With reference to the criticism as to the rates of filtration at which the various substances had been tested, of course to make the enquiry absolutely complete every conceivable rate should be tried for every individual substance. He thought, however, that the first way of attacking the question was to use the same depth of each substance, and to make the rate as nearly constant as possible, and even that was a matter of great difficulty. One point had been brought forward by Mr. Anderson which he most emphatically challenged—that it was of the greatest consequence to purify water chemically, because, if it was so purified,

Dr. P. Frankland.

[1] Journal of the Chemical Society, vol. xxxix. 1881, Transactions, p. 247.

Dr. P. Frankland.

the organisms, notably the pathogenic organisms, could not exist in it. That was likely to give rise to serious misunderstanding. Although he did not agree with Mr. Jabez Hogg that these organisms were capable of enduring strong nitric acid, yet he was strongly of opinion, and he knew it as the result of experiment, that pathogenic organisms could be kept for a long period of time alive in pure distilled water. He did not believe that purification by agitation with iron, or by filtration through particles of iron, would render water as pure as distilled water, and he did not think that water which was chemically pure could be considered safe on the ground that micro-organisms if afterwards introduced would not live in it. It had been stated that Dr. Klein had remarked that septic organisms were absolutely fatal to pathogenic organisms; but he certainly did not make such a sweeping statement. He said that there were some experiments which seemed to show that some pathogenic organisms were destroyed by septic organisms. That that took place with the extraordinary rapidity implied by Mr. Ekin's observation was certainly not the case. If some pathogenic organisms were placed in a given medium with septic organisms, and they were allowed to enter into competition, in all probability in the course of time the pathogenic organisms would have disappeared, and the septic organisms would have gained the mastery, but there was no evidence that all pathogenic organisms would behave in that way; and in the present incomplete state of knowledge it was highly undesirable to place any reliance on such fragmentary observations.

Sir Frederick Bramwell.

Sir FREDERICK BRAMWELL, President, said he feared that as a practical body the meeting could not help feeling troubled at the want of result attendant on the Paper and its discussion. He thought it was not too much to say that it had been left an open question as to whether the organisms did any harm, whether if some were harmful others were not innocent, whether there were not some organisms which destroyed others, and whether it would not be well to leave the destroyers in the water so that they might destroy. Nobody knew which were the bad and which were the good, or whether the bad would eat up the good, or the good eat up the bad. He would ask anyone, (except perhaps Mr. Mansergh, who had swallowed twenty-three millions of organisms without feeling any the worse for it), whether on going home he would be prepared to drink a glass of water, even if treated with strong nitric acid. He felt in the most complete state of confusion, and more inclined than ever to adhere to the practice of never drinking water unless it had been boiled.

Seriously the Paper and the discussion were enough to cause great alarm by showing the danger of drinking polluted water; but having excited this alarm he could not find that any remedy was agreed on by which that alarm might be satisfactorily allayed. Sir Frederick Bramwell.

Correspondence.

Mr. H. K. Bamber contended that the microscopic living organisms found in water were perfectly harmless if taken into the stomach, where they would perish almost immediately. He believed they might be looked upon as the first of a series of beings ordained to live upon what otherwise would become injurious to mankind instead of food. The mere fact of their being able to live and multiply so vastly in water showed that water was their proper element. When the water stood in the storage tanks or reservoirs of the water companies, these organisms had all the circumstances necessary for their rapid growth and multiplication, and on the water being passed on to the filter-beds, they could move and keep themselves above the sand, without being drawn through with the water, as dissolved organic matter would be. This might account for their number being so much less in water that had passed through the filter-beds. He would ask the Author how long the filter-beds had been renovated before he tested the water, and what would be the effect on the water when the sand was near its time for renewal? Of course the great object of filtration was to prevent river-water from becoming contaminated in times of epidemics, when probably vast quantities of disease-germs passed into the rivers. Mr. Bamber.

Mr. Henry Gill, Director of the Berlin Municipal Waterworks, directed attention to the subjoined abbreviated Report by the German Imperial Board of Health, on the results of the chemical and biological examination of the Berlin water-supply. The general description of the works given in the Report was correct, but the opinions expressed respecting the quality of the well-water must be received with caution. In order to bring up the information concerning the works at Berlin to the present date, he might add that in April last the funds for the completion of the waterworks scheme in the Havel basin, projected so long ago as 1874, had been voted, and the works, which would exhaust the available capacity of the Havel, would be finished in the autumn of 1887. Tegel would then possess 49,000 square metres of covered filter surface, divided Mr. Gill.

Mr. Gill. into twenty-one distinct filters, with a daily yield of 90,000 cubic metres, for distribution from the Charlottenburg station. Filtration through quartz sand was the only method of purification adopted at Berlin. The sand-grains varied in diameter from ½ to 1 millimetre. The thickness of the layer (normal) was 62 centimetres. The uncovered filters were of the usual form; the covered filters were, when filled and in action, covered reservoirs. Each of the Tegel filters had a chamber at the delivery end of the filtered water canal. From this chamber the filtered water was discharged through an orifice in a thin plate into the air; the level of the water above the centre of this orifice could be regulated by a sluice. The sand area and the area of the orifice being known, and a given yield per unit of sand area having been fixed upon, it was easy to determine by calculation, and to test by experiment, the height of the water above the orifice necessary to give the prescribed yield. Floats indicated on scales attached to the walls—

(*a.*) The level of the water in the filter above the sand;

(*b.*) The level of the water in the chamber on the filter side of the regulating sluice; and

(*c.*) The level of the water in the chamber on the exit side of the regulating sluice.

It was the duty of the filter-attendant by means of the sluice to keep this last level a "constant" for a given yield per sand-area unit. In the Tegel filters this constant was fixed at about 90 centimetres beneath the lip of the overflow of the filter. This limited the effective head of the water acting on the sand to 90 centimetres, and during the life of the filter this head might vary from 0 to 90 centimetres. This arrangement was altogether wanting at the Stralau station, and only estimates were possible for the head and speed of those filters; the figures given for the Tegel filter were, however, absolutely reliable.

The results given in the Report respecting the comparative efficiency of the covered and uncovered filters at Stralau had been a surprise to all concerned; it had been impossible, however, to repeat the tests, nor would it be possible to renew the experiments before 1887 when the new works were completed. Suppose the observations as to speed and pressure for both filters, as given in the Report (p. 16) to be correct, the explanation of the unexpected results might lie:—

(*a.*) In the season, as influencing the condition of the unfiltered water during the period of the experiment; or,

(*b.*) In the condition of the filters themselves.

(*a*.) From the 3rd to the 12th of September the blossoming of the water (*Wasserblüthe*) had not quite ceased. This blossom consisted of minute vegetable organisms, like fish-scales, which permeate the entire volume of the water. On entering the covered filter they would be removed from the influence of the sun, and further development would probably cease. They would then fall to the sand at the bottom without any increase in number or size, and would form a comparatively thin and weak matting or intercepting medium for the retention of the microphytes. In the uncovered filters the sun would act on these plant-organisms and cause a vigorous increase both in size and numbers, and consequently a comparatively compact and thick matting for the retention of the microphytes. Mr. Gill.

(*b*.) The condition of the two filters was known to be very different. All the filters of the station had been very heavily and unfairly worked, No. IV. to the death. Before the commencement of the experiment it had been completely renewed, not with new sand, because the old sand, even after twenty-five years' service, after the removal of the upper crust, proved, under the microscope and in the washing test, to be good. It was, however, ridged and furrowed down to the gravel, and daily turned over for some weeks, until the whole mass had been thoroughly acted upon by the sun. It was then trimmed flat, and carefully rolled with a light iron roller. This sand, although not sterile, might be termed almost so as compared with that of the covered filter with which it competed. The speed of filtration at Stralau was 1·56 gallon per hour per square foot, while the speed at Tegel was 2·5 gallons per hour per square foot of filter surface—a speed rigidly adhered to at all times, and never exceeded during the life of the filter. The experiments at Tegel did not prove that the efficiency of the filter decreased, as respected removal of microphytes, with age. The daily fluctuations in this respect were due to causes which were not yet apparent. The fluctuations in the quantity of microphytes in the unfiltered water were probably due to atmospheric influences—the sun, and especially wind. They appeared to be independent of temperature; remaining relatively the same whether the temperature of the water was 24° Centigrade or 8° Centigrade. Only those micro-organisms were considered by the Imperial Board of Health to be "suspicious" which caused the gelatine to liquefy in the test-process. The instructions given to the engineers in charge of the filter stations contained minute directions for the running off of the water from dead filters to aerate the sand; for the removal of the upper layers

Mr. Gill. of the sand for cleansing; for the method of refilling them from beneath the sand with filtered water, up to a level of 10 centimetres above the renewed sand; for running the water first drawn to waste, at a slow rate, for forty-eight hours, and for the attainment of the full speed of 125 millimetres per hour, only after three, four, or more days of working. The sand was washed in a revolving drum, making five to seven rotations per minute, and was further cleansed by a jet. Sand thus treated, when put into a tumbler of water and stirred with a glass rod, must produce no turbidity nor discoloration of the water. The ordinary modes of washing the sand, such as the water-jet, overflowing boxes, &c., failed to cleanse it from the impurities resulting from the filtration of the water of the North German Steppe so thoroughly as did the plan in use at Berlin, which plan had also been adopted in all parts of Germany.

One of the most important factors in the process of filtration was, in accordance with the experience gained at Berlin, unchanging speed of filtration, or avoidance of increase of speed, during the life of the filter. The micro-organisms were, in the earlier stages of their attachment, feebly adherent to the grains of sand, and a slight increase in speed of filtration, especially if it were sudden, detached them and scoured them away into the filtered water canal. Other matters dealt with in the German report, notably the attempt to use underground water, were only of exceptional and local significance. The remarks of the Author, that engineers in charge of the water-supply of cities must devote careful attention to the micro-organisms, were justified by experience. This view had been taken by the Municipality of Berlin, and an examination, both chemical and biological, of the water-supply had been ordered at intervals of fourteen days. On the advice of its Director, moreover, the Stralau station had been furnished with a properly-equipped laboratory, and biological examinations of the water were now made daily by the engineer in charge of the station, who had passed a period of training under Dr. Koch to qualify him for these duties. It must be remembered that the development of the micro-organisms in the nutritive fluid was probably much more rapid than in the parent water, and that the test-culture gave only comparative results. In moderately skilful hands the test gave a very trustworthy insight into the efficacy of the cleansing process.

It appeared doubtful whether filtration alone, unless practised at a prohibitively slow rate, could be relied upon to remove completely microphytes and their spores. These were so minute that

unless entangled and held in a precipitate, they were liable to be carried through the sand. If absolutely or practically microphyte-free water were insisted upon, a chemical process must precede the filtration. For the treatment of the water with iron, which, as now practised at Antwerp, appeared to be a step in the right direction, a trial filter, of 75 square metres in area, had been constructed at Stralau, the apparatus for the purpose being kindly lent by Messrs. Easton and Anderson. Mr. Gill.

Investigations of the Imperial Board of Health respecting the Quality of the Berlin Water-Supply between July 1884 and April 1885.

Dr. G. Wolffhügel (Reporter).

The Waterworks of Berlin.

Two great works supply the water used in Berlin for domestic and drinking purposes, one of which, situated at Stralau, utilizes the water of the River Spree, the other is fed from Lake Tegel. In both works the purification is effected by means of filtration through sand, and the water is raised and distributed by steam power. The water from the Stralau works passes directly into the town mains, but that from Lake Tegel is delivered into a compensation-reservoir at Charlottenburg and from thence raised into the system of mains. A portion of the town is supplied by a high-pressure system, the works for which are situated in the Belforter Strasse, the water being that from Lake Tegel. The daily volume of water required per head amounted for the year ending March 31st, 1884, to a mean of 63·57 litres, the maximum being 95·47 litres, and the minimum 46·94 litres. The Stralau works have been in operation since 1856, and consist of eight open and three covered sand-filters, with a total area of 37,500 square metres. As the normal rate of filtration amounted, based on the quantity of water used, to 0·12 to 0·13 metre per hour, it would seem that from 2·88 to 3·12 cubic metres are purified daily per square metre of area. The volume of water consumed daily from these works reaches a maximum of 70,000 cubic metres and a minimum of about 30,000 cubic metres. The works on Lake Tegel have been connected with the pumping station at Charlottenburg since September 1877, but the water has only been drawn from the lake since November 1883, previous to which date the supply was derived from twenty-three wells sunk on the low ground near the lake, some of them being as much as 26 metres in depth. The quality of this well-water was at first very good, but after ten months' working, in the summer of 1878, a marked pollution due to the vegetable growth, rich in iron, of the *Crenothrix polyspora* became noticeable. In the following years this growth increased, and gave rise to much complaint in the town. Though it cannot be shown that this organism was in any way injurious to health, its presence caused the water to be rejected for many domestic purposes, and indeed rendered it useless. Various means were devised to combat this evil, but all of them proved fruitless, and it became recognized that the growth was owing to the use of wells. Ultimately it was resolved, in March 1882, to abandon the wells and to obtain the supply direct from the lake A sum was voted for the construction of ten covered filter-beds, with a total area of about 20,000 square metres, on the completion of which, in November

Mr. Gill. 1883, it became possible to obtain the supply from the lake instead of from the wells. A normal speed of 0·125 metre an hour was fixed upon for the rate of filtration, so that the average yield per square metre of filter is 3 cubic metres per diem. The actual volume of water distributed by these works amounts to between 42,000 and 45,000 cubic metres. From 1882 to April 1884 seven new covered filter-beds, a second double reservoir for filtered water, together with the requisite buildings and pumping machinery which were to be completed by July 1885, have been ordered. The addition of four more filter-beds is under consideration, on the completion of which these works will be able to furnish 90,000 cubic metres of water per diem.

The quality of the water is tested each week by the municipal authorities. Until 1884 the tests were mainly chemical, but since July 1884, an arrangement has been made by which both chemical and biological examinations of the water-supply are conducted by the Imperial Board of Health. Since June 1, 1885, these tests have been entrusted to the Hygienic Laboratory of the University. Samples are taken each week from ten different localities, in accordance with regulations laid down by the chemists of the Board of Health. And some special series of daily tests have been undertaken to investigate the yield of individual filter-beds, and the quality of the filtered water under varying conditions as to endurance, &c. For this purpose daily samples were taken of filtered and unfiltered water.

The weekly tests extended to the examination of the water as respects temperature, colour, freedom from turbidity, taste and smell; the contents in micro-organisms; as also to its chemical composition (qualitatively chlorides, sulphates, nitrates, nitrites, sulphuretted hydrogen, ammonia, lime, iron; quantitatively residue, loss on combustion, chlorine, nitric acid, ammonia, lime, and oxydisability).

In the investigation of the water, the colour and clearness, seen through a depth of 20 centimetres, were first noted; also its taste and smell when cold and after being heated. The chemical tests are also given at length.[1]

The biological examination was carried out both with the microscope and by means of pure cultivation with ten per cent. meat-juice-peptone-gelatine, 1 cubic centimetre of water being employed. The microscopic tests made after the preparation had been coloured, were conducted with a drop of the fresh water on a covered glass slide and also with the residue from the same water, after standing for some time in a glass vessel. At first the residue was taken after standing for fourteen days, but latterly it has been examined after standing only twenty-four hours, owing to the rapid growth of vegetable organisms, which rendered the investigation a work of great difficulty.

The results of the analyses, which for want of room could not be repeated, are given as monthly averages in a series of Tables too long to abstract. In addition to the Tables, a series of six diagrams, showing the results in graphic form, have been prepared, which represent the effects of sand-filtration very plainly. It has, however, been found impossible to adopt the same scale for representing numbers of microphytes in the filtered as in the unfiltered water in all cases, owing to the wide differences between the figures.

From these Tables it will be seen that the fluctuations in the chemical composition both of the water of the Spree and in that from Lake Tegel are but slight, with the sole exception of Tegel water-tests during the month of February. The contents in micro-organisms vary much more considerably.

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[1] Minutes of Proceedings Inst. C.E. vol. lxxvii. p. 426.

The effect of the filtration through sand is in the first place to cause a marked improvement in the external characteristics of the water (colour, taste, and smell). The results of the chemical and biological tests showed that a regular and well-defined improvement had taken place in each case, with the exception of a period during March 1885, when, owing to the freezing of the Stralau filters, the percentage of micro-organisms was unusually high. To watch the actual working of the various filters, daily examinations were made of the filtered and unfiltered water both at Tegel and Stralau in the months of July, September, and October. In the course of these trials it was found that in the comparative tests of covered and uncovered filter-beds at Stralau, the open filter-bed, No. IV., removed the micro-organisms much more effectually than the covered filter-bed, No. IX., with which it was compared. The number of germs capable of further development in unfiltered and filtered water being as shown in the accompanying Table. Mr. Gill.

STRALAU WATERWORKS.

Date.	Speed per Hour.	Head of Pressure.	Water, unfiltered and filtered.	Number of Germs of Microphytes in 1 Cubic Centimetre of Water. Total Number.	Number capable of rendering Gelatine Liquid.
	Metre.	Metre.			
Sept. 3	0·083	0·47	Unfiltered	1,056	63
			From covered beds	108	21
			„ open beds	23	5
„ 4	0·094	0·44	Unfiltered	1,435	83
			From covered beds	41	9
			„ open beds	12	2
„ 5	0·088	0·39	Unfiltered	3,052	243
			From covered beds	81	14
			„ open beds	16	9
„ 6	0·082	0·47	Unfiltered	3,766	63
			From covered beds	184	18
			„ open beds	11	4
„ 7	0·062	0·34	Unfiltered	4,320	62
			From covered beds	134	8
			„ open beds	14	7
„ 8	0·071	0·36	Unfiltered	1,162	41
			From covered beds	112	48
			„ open beds	28	6
„ 9	0·078	0·46	Unfiltered	1,760	40
			From covered beds	127	11
			„ open beds	16	5
„ 10	0·084	0·52	Unfiltered	2,078	72
			From covered beds	144	6
			„ open beds	30	4
„ 11	0·087	0·53	Unfiltered	3,465	70
			From covered beds	111	4
			„ open beds	31	5
„ 12	0·085	0·55	Unfiltered	3,535	88
			From covered beds	117	8
			„ open beds	15	3

Mr. Gill. These observations, taken in connection with the monthly averages, tend to prove the very remarkable diminution of micro-organisms after simple sand filtration. Observations follow respecting the occasional presence of the *Crenothrix polyspora*. It is established beyond a doubt that various impurities are taken up by the water during its passage from the filter-beds to the centre of the town. In the Charlottenburg reservoirs such highly organized forms of insect life as *Daphnia pulex*, *anguilula*, &c., have been noticed. But in no single instance have the water-tests, either chemical or biological, given any grounds for the belief that the Berlin supply contained any matters injurious to health. That is to say, that none of the micro-organisms have, on pathological grounds, revealed any indications of a dangerous character. The report contains very numerous tables of analyses and six sheets of diagrams.

Mr. Higgin. Mr. G. Higgin observed, in reference to filtration through sand, that seven or eight years ago he had occasion to make a series of experiments in filtration, with the object of ascertaining the best method of purifying the water of the River Plate, which was used for the supply of Buenos Ayres.[1] It was stated in the Paper that the London Companies succeeded in eliminating 96 per cent. of micro-organisms from their water by means of a simple filtration through a bed of fine sand from 3 to 4 feet thick, at a speed of from 1½ gallon to 2 gallons per square foot per hour. If this was so, it seemed evident from his experiments that the engineer might be called upon to deal with suspended particles smaller even than micro-organisms, and for whose elimination sand-filtration was useless. The River Plate was a delta-forming river, and like all rivers of that class, its waters are highly charged with suspended matter. Simple repose for twenty-four hours was sufficient in most cases to allow of the deposition of the greater part of this suspended matter; but there remained behind matter in suspension in a state of most minute subdivision, and giving a yellowish opalescent character to the water, which it appeared almost impossible to get rid of. Passing it through three folds of fine filter-paper had no effect on it. Repose for three or four months made scarcely any appreciable change in its condition. Filtration through 3 feet of fine sand, at a rate so low as ½ gallon per square foot per hour, effected no material improvement. He had not the means of examining this water by the gelatine process. In fact, at that time he believed this process was not known; but judging from the Author's experiments on the London waters, it was reasonable to suppose that he also must have eliminated from 90 to 96 per cent. of the micro-organisms; but he had certainly not removed more than 2 or 3 per cent. of the fine suspended matter. It seemed, therefore, that this matter was divided into particles

[1] Minutes of Proceedings Inst. C.E. vol. lvii. p. 272.

considerably smaller than micro-organisms, as they were not intercepted by a sand-filter. He ultimately succeeded in discovering a medium that answered perfectly. By introducing a thin layer of pounded cinders in the sand he completely removed the yellowish opalescent character of the water, and obtained a brilliantly pellucid water, which, tested by Professor Wanklyn's system of analysis, the only one available, showed that the albumenoid ammonia, which existed in the original water to the extent of 0·24 part per million, had been reduced to 0·01 part per million. He obtained this result with the filter running at the rate of 5 gallons per square foot per hour, or say about three times the speed of the London filters, and ten or twenty times that used by the Author in his researches, and he believed even a higher rate than 5 gallons could be obtained, and that it would not be necessary to have a greater depth of sand than 1 foot, with a layer of pounded cinders 3 inches thick in the middle. The question of speed was a very important one for the practical engineer. It would, of course, be impracticable to build filters to run at the rate used in the Author's experiments. For all practical purposes a rate of 2 gallons per square foot per hour was as low as could be conveniently used for works which were to be self-supporting or paying concerns. With a lower rate than this, the cost of the filters would be in many cases prohibitive. If, as he believed, a better result could be obtained by the use of the material he used with a speed of 6 gallons, the cost of the filters might be reduced by two-thirds, whilst another reduction would be brought about by the less depth of sand required. It was still an open question whether the presence of micro-organisms in water was noxious or not; but there was, he conceived, no doubt that noxious germs could be carried in water, and so introduced into the human system; especially was this the case in such diseases as cholera. Undoubtedly water was the best medium for propagating cholera germs or poison; but it was satisfactory to know that these poisons or germs were not the result of spontaneous generation. In the case of Asiatic cholera, for instance, in order that the water should be poisonous, it must in the first instance have been inoculated with the specific choleraic poison. Engineers should, he thought, therefore, wherever possible, seek for a water-supply the source of which was not likely to be contaminated by any specific poison. Filtration was at the best but an unsatisfactory mode of purification, doubtful in its results, even under the most careful management. It was not known at the present moment whether the choleraic poison or germ could be removed by any filter; nor was the peculiar germ known, for Dr. Koch's Comma

Mr. Higgin.

Mr. Higgin. Bacillus had not yet been accepted by the scientific world as the specific cause or concomitant of cholera. In reference to this view of the case, he should like to direct attention to water-supply as affecting cholera, as shown in the recent cholera epidemic in Spain. He would especially refer to the cities of Malaga, Seville, and Toledo. None of these cities had any satisfactory drainage, and their sanitary condition was as bad as could well be. The first two had a climate almost tropical, and in Seville typhoid fever was endemic. Cholera was present in Toledo during the last two summers, but it never became epidemic, and rarely passed beyond one or two cases per day. Malaga had the cholera in its midst during the whole of last summer, but it also never became epidemic or severe. In Seville the cholera appeared in the autumn of last year, but it disappeared after a few cases. Toledo, at the time the cholera appeared, was supplied with water from the River Tagus; but immediately on the outbreak of the disease the governor stopped the engines at the waterworks, and obliged all the inhabitants to send for water to a spring at some distance off. Malaga had lately been provided with an excellent supply of fine spring-water, and on the outbreak of the disease the inhabitants were prohibited from using any other water but this. The inhabitants of the suburb of Triana, at Seville, used to drink the water from the River Guadalquiver, but so soon as the disease broke out in the province, the authorities strictly prohibited the use of the river-water; they laid pipes across the bridge, and opened taps of the Alcala water for the use of the inhabitants; and in order to prevent any contamination at the sources of this water, civic guards were put on day and night to guard them. He would contrast with these cities the lamentable loss of life in Granada, Zaragoza, Aranguez, and other places where the water-supply was derived from open canals, liable to all classes of contamination. In the present state of ignorance in regard to water, he thought engineers should, wherever it was practicable, avoid filtration altogether, and seek for a source of supply not liable to be contaminated by any specific poison.

Rev. A. Irving. The Rev. A. Irving was unable to give his full assent to the proposition (p. 200) that the biological side of it "is now nearly, if not quite, as tangible as the chemical side." Several considerations suggested themselves, which rather induced the belief that the biological study of the living primordial organisms, which abounded in many waters, was only as yet in its infancy. Until the life-history was more fully worked out of at least the principal species of germs, including the several kinds of organic

matter upon which they severally depended for subsistence and development, the phases of existence through which they passed, the physical conditions (temperature, light, &c.) upon which they depended for their vital activity, the classification (or at least an approximation to a classification) of them into Pasteur's two categories of (1) aërobic organisms, and (2) anaërobic organisms, it could scarcely be said that the biological study of this subject had a claim to be considered as a part of exact science. Perhaps it might ultimately turn out that these two classes of organisms were only metamorphic phases of the continuous life, in many cases, of individuals of one and the same species. This was merely pointed out as an example of some of the interesting questions which arose in connection with the biological side of this subject, and had a direct bearing upon its application to sanitary science. It might well happen that a micro-organism, which was inactive in a sample of water destitute, or nearly so, of atmospheric oxygen in solution, might assume a state of considerable activity if that water became oxygenated by exposure to the air, and consequent absorption of oxygen. This activity might render it injurious in one species, while in another it remained totally innocuous in its active state. Again, a species capable of acting injuriously upon the alimentary canal of the human subject might be harmless if received into other animal organisms, and the converse of this was equally true. And, once more, it was quite conceivable that a microphyte, inactive within the ordinary range of temperatures of natural waters, might become active, perhaps injuriously so, at the temperature of the human body. These were some of the points which had to be dealt with as the whole life-history of these organisms came to be worked out. There would seem to be, therefore, grave reasons for doubting the wisdom, in the present state of knowledge, of laying stress, as was sometimes done, upon the absence (or exceeding paucity) of moving organisms in some potable waters. It was quite conceivable that a water charged with vegetable matter might be sterile to living aërobic germs, or contain them in an inactive condition (that was, with their powers for mischief latent) from its mere deficiency in free oxygen, owing to the consumption of this gas in the slow oxidation of the dead organic matter present. If this were so, it by no means followed that such organisms would not become active, and in some cases injuriously so, when such waters became oxygenated. The importance of recognizing the principles and cautions suggested above seemed to receive a curious illustration from one of the facts tabulated by Dr. Frankland, p. 220 of the Rev. A. Irving.

Rev. A. Irving. Paper. The substitution of a multiplying power of 447 per cent. at the end of one month, for a reducing power of 100 per cent. in fresh animal-charcoal, was strongly suggestive of the occurrence, in this instance, of organisms belonging to the vegetable kingdom, and as such probably innocuous. It was a common experience in chemical laboratories to find such organisms developed in great numbers in such re-agents as sodium phosphate, from the spores which had found access from the air to the bottles holding these solutions; and calcium phosphate, which was always present in animal charcoal, was an ingredient of both Pasteur's and Mayer's solutions, which were used by students of biology for the cultivation of minute vegetable organisms. With the present extensive use of animal charcoal as a filtering medium, the statement referred to, as it stood in the Table, would be rather alarming if these considerations were overlooked. It would be interesting also to learn whether, in the actual experiments upon which the statement was based, the organisms were green or colourless, and whether the experiment was conducted in a glass vessel or in one made of opaque material, the formation of chlorophyll, and consequent assumption by vegetable organisms of a green colour, depending, as was very well known, upon the access of light. Before leaving the biological side of the subject, it might be as well to point out, that which was well known to those who had followed the public discussion, in "Nature" and other Papers, of the methods and results of Dr. Koch's work, that the conclusions of that gentleman could scarcely be said to have received anything like that unqualified assent which certain paragraphs in the Paper would seem to imply, from the ablest bacteriologists in this country and in France.

Turning now to the chemical side of the subject, he might be allowed, perhaps, to state *in limine* that he had been led to the study of this, incidentally, through his researches in the history of the Bagshot Sands, leading to the discovery of the organic origin of the green colouring matter, which abounded in certain strata of this and other tertiary formations. He spoke, therefore, with entire freedom from any bias which might be expected in a professional expert. The judgments given by those gentlemen were professional indeed, but often empirical to a degree. It was in the early part of the year 1883 that he began to investigate the cause of the greenness of certain beds in the Bagshot strata, and the results obtained in this investigation soon led him to suspect the real nature of the impurity of the water from the deep well on the estate of Wellington College, which, by its corrosive action on iron pipes, and the prevalent inky taste it imparted to the water,

had been for several years a source of great inconvenience, even if no worse results had followed from it. This suspicion was soon confirmed by the special chemical tests for the humus acids applied to samples of water taken directly from the well. An extension of this investigation, during the summer of that year, showed the wide prevalence of these humus, or peaty acids, in the waters drawn from numerous wells in the middle and lower Bagshot strata, as also in the water of wells in the upper ferruginous sands, where the conditions as to depth, &c., were such that the water was affected by the soluble products of decay of the vegetable matter contained in the forest-litter of these ancient forest lands. The first results of the inquiry were drawn up for the use of the Governors of Wellington College, and the sanitary engineer whom they consulted; they were also published, in their geological as well as in their sanitary bearings, in the "Geological Magazine" of September 1883, and January 1885. He had already pointed out,[1] in one of the Papers above referred to, how unusual it was to see in returns by professional analysts any note as to the nature of the vegetable pollution of water (though the presence of such matter was frequently indicated), and the desirability, in all cases, of the analyst directing his attention to the vegetable or animal origin of the organic matter contained in any given sample of potable water; also the necessity, especially in dealing with single samples, of having regard to the time which elapsed between the collection of a sample and its systematic examination, owing to the changes in composition which organic compounds produced during decay of vegetation in water underwent by exposure to atmospheric oxygen. A case was then cited by him, in which a water drawn from a well with a strong marshy flavour and odour, and proving, on examination, to contain a very considerable quantity of one of the humus acids in solution, was reported by a professional analyst to be "very free from organic pollution." Rev. A. Irving.

One or two instances of a similar character, which had occurred in his more recent experience, might be mentioned, names of persons and places being for the most part omitted, for obvious reasons.

1. A sample of well-water was brought to him, during last year, from a vicarage in the marshes of the Avon. This sample was at once examined, and, though perfectly clear to the eye, proved to be loaded with crenic acid. After standing for some days it became turbid, and yielded a copious flocculent deposit.

[1] "Geological Magazine," decade iii. vol. ii. p. 21.

Rev. A. Irving. 2. Later in the year some samples of water were sent to him for examination from another district. Strange to say, though this water was distinctly a peaty water, and acted rapidly upon iron pipes, it was favourably reported on by three professed analysts, one of whom admitted that he had not examined the water for humus acids, and had only made "the ordinary analysis." An analysis of some samples of the ochreous deposit, which this water produced, gave 13·4 per cent. of organic matter; and during the extraction of this from the red deposit by decoction in potash-solution, the odour (partly aromatic, partly earthy) was so strong that the laboratory became well-nigh unbearable, until the operation was transferred to the draught-cupboard.

3. Having to depend upon a soft-water supply at Castle Malwood, Sir William Harcourt had experienced the difficulty and inconvenience which arose from the presence of humus acids in such waters, where a sandy sub-soil overlying clayey strata, in a district which had been for centuries covered with forest-litter supplied water to shallow wells highly charged with such acids. The action of this water upon metal pipes was, on examination, soon explained by the presence of the humus acids, which a chemical examination of the water revealed. Of the different waters of which samples were examined from that locality, and of which samples had been previously analysed by the chemist of a government office, one was found by that gentleman to have received "a large amount of animal contamination," and was condemned by him, though its action upon lead and zinc was found to be very slight indeed. The other water was much more energetic in its action upon a new leaden pipe, and remarkably so upon an old leaden pipe; and this action was not wholly removed after rapid filtration through animal-charcoal. The presence of peaty acids in this water, as the true cause of its solvent action upon metals, seemed again in this case to have been overlooked; and the water being "quite free from evidence of sewage or other animal contamination," was returned as "of excellent quality for drinking-water."

4. During last winter Professor Graham, of University College, mentioned to him the case of a specimen-plate of an engine-boiler, which had been sent to him from Glasgow, and was corroded through a great part of its thickness, which he attributed to the action of the peaty acids contained in the water of Loch Katrine. Not further to multiply instances, it was only necessary to refer to the peaty character, which Professor Wanklyn has proved to belong to water obtained from the moorlands of North Derbyshire

for the supply of Manchester; and he had himself observed the difficulty hitherto experienced in the removal of humus acids from the water obtained from the surface-drainage of a large area of country, and supplied to one of the largest towns in the Midland Counties. Rev. A. Irving.

As he had elsewhere pointed out, the conditions of soft-water supply were such that in the vast majority of instances contamination by humus acids was unavoidable, and it would almost seem that the effectual removal of them without introducing other sources of contamination, or giving the water a chalybeate character, was the chief remaining difficulty of water-supply. This difficulty, however, he had found to be surmountable by the adoption of the process which he had himself patented. Notices of this had already appeared in most of the periodicals devoted to engineering and sanitary science. It was only necessary to note here the fact, that, recognizing the action of the humus acids upon metallic iron, to form neutral salts soluble in water, also the rapidity with which most neutral ferrous salts were broken up by oxidation of the base, and its precipitation, partly as ferric hydrate, partly as basic salts of iron; the feature which especially distinguished this process was the combined action of iron and atmospheric oxygen systematically applied to the purification of peaty waters. It was also to be remarked, that, as any form of scrap iron could be used, the expensive process of preparing chemically-reduced iron was rendered unnecessary; while the factor of time (so important for the completion of chemical change) was fully allowed for. A more complete removal of the peaty acids by saturation with iron was thus secured by a steady flow, allowing time for molecular diffusion, than could possibly be attained by mechanical agitation of the water with metallic iron. Without due account being taken of this factor of time, both for the complete saturation of the acids by the metal, and the complete removal of the iron by precipitation and (if necessary) mechanical filtration, the results could hardly be satisfactory.

It was no part of his purpose to attempt to raise a scare about humus acids, although he could not fail to see that some mischievous results had followed from the presence of them in most soft waters, and from their chemical action being so generally ignored. He was aware that they had received hitherto little attention in this country; in fact, he had known chemists of some repute scoff at the bare idea of their possessing any power for mischief, and call in question the very existence of some of them. On the Continent, however, and more recently in America, they

Rev. A. Irving. had received more attention; and it might be as well to remind English chemists of their recognition by Fresenius in the latest edition of that portion of his Quantitative Analysis, which was devoted to the analysis of water, as well as of the researches of Berzelius, Mulder, Boutigny, and others, published years ago. Perhaps the most complete account of them in the English language was to be found in an exhaustive Paper by Alexis A. Julien, in the Proceedings of the American Association for the Advancement of Science for 1879.[1] Their effects upon the human economy would seem to be twofold: first, indirectly, by taking up various metals (notably iron, lead, and zinc) to form soluble salts of those metals, and in this most dangerous of all forms introducing them into the system. On this point it should be borne in mind, that it was only the least harmful of the three metals mentioned (iron) which could be readily removed from solution by a process of oxidation. Secondly, directly, by a slow but continuous action, perhaps as reducing-agents diminishing the quantity of oxygen in the blood, upon which its vital action so greatly depended, and thereby rendering the system more liable to succumb to the attacks of disease; or, it might be, by tending to neutralize the alkalinity of those secretions upon which the formation of chyle (the necessary antecedent to assimilation) so greatly depended;[2] it being a matter of common experience, and established as a scientific truth by Pasteur, that a strong and vigorous state of health tended to ward off the effects of disease germs, to which persons of more feeble vital powers succumbed. On this point, however, he would speak with much reserve, until the idea, which was here somewhat crudely expressed, should be verified by further research. Yet there were facts known to him, which certainly pointed to a possible connection between the use of waters charged with peaty acids by the population of certain districts, and the localization of some zymotic diseases.

In conclusion he had only to point out that in the light of present knowledge, and with the processes now available for their purification, the common prejudice, which existed against soft waters *per se* for dietetic purposes, was unfounded; the corrosive action of such waters upon poisonous metals being mainly due to the presence of peaty or humus acids, which could be effectually removed, both on the large and on the small scale. If this were admitted, he might perhaps be justified in asking engineers to

[1] "On the Geological Action of the Humus Acids," p. 311.
[2] T. H. Huxley, Elementary Physiology, 1st edition, p. 160.

consider the advantages of utilizing, more than had been hitherto done, for the supply of large centres of population, the waters of moorlands and natural lake-basins, and of providing effective means of purifying and storing such waters, since, as regarded animal contamination, such supplies of water were unimpeachable. Rev. A. Irving

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13 April, 1886.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The discussion on the Paper on "Water-Purification," by Dr. Percy F. Frankland, occupied the entire evening.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2143.*)

"Blasting-Operations at Hell Gate, New York."

By LEVESON FRANCIS VERNON-HARCOURT, M.A., M. Inst. C.E.

THE passage between New York Harbour and Long Island Sound was obstructed by numerous reefs, scattered across the East River between Astoria on Long Island and the opposite shores at New York and Ward's Island (Plate 6, Figs. 1 and 4). These reefs not merely constituted in themselves a danger to vessels, but also imperilled navigation by causing rapid tidal currents in the narrowed channels between them, attaining in places a velocity of 8½ knots an hour. Wrecks were consequently of frequent occurrence; and the name of Hell Gate was appropriately given to the locality. Three channels existed past the reefs, namely, the main ship channel to the north-west of the Heel Tap and Mill Rocks; the middle channel between the Mill Rocks and the Middle Reef; and the east channel between the Middle Reef and Astoria, from which Hallett's Reef projected; and vessels, after having traversed one of these channels, had to avoid Hog's Back and several smaller reefs to the north-east of Hallett's Point on their way to sea. Vessels approaching New York by the main channel had to make such a detour to avoid Heel Tap Rock, that they were liable to be drifted by the current towards Rylander's Reef: the eddy produced by Hallett's Point rendered the most direct east channel very difficult to navigate, for vessels in avoiding Hallett's Reef were in danger of being driven on to the Gridiron Rock of the Middle Reef; and the middle channel was narrow.

When the first proposals were made for improving Hell Gate, in 1848, the cost of removing submerged rocks was so great that the lowering of the most dangerous peaks, by surface blasting, was alone suggested; and this system was adopted between 1851 and 1853. After this no further steps were taken till, in 1867, General Newton reported in favour of a comprehensive scheme of improvement by the removal of Hallett's Point, Middle Reef, and several smaller rocks, to a depth of 26 feet at mean low-water; and he

proposed that Pot Rock, Frying Pan, Way's Reef, and Shelldrake should first be removed, and that the more extensive improvements suggested should be deferred till cheaper processes were devised by extended experience.[1] Works were undertaken in 1868-9 for the removal of the four smaller reefs above mentioned, which originally had depths of only from 5 to 9 feet of water over them, and had been lowered from 8 to 12 feet, in 1851-3, by exploding cans of powder placed in contact with the rock, at a cost of £2,420. The areas of these rocks at the 26-foot contour, and their contents above that depth, together with Heel Tap Rock whose removal was recommended, were estimated in 1867 as follows:—

	Area.	Contents.
	Square Yards.	Cubic Yards.
Pot Rock	1,347	1,170
Frying Pan	1,386	1,910
Way's Reef and Shelldrake	689	1,640
Heel Tap	2,555	1,960

Surface blasting involved a large expenditure of explosives in proportion to the results obtained, and was only applicable to slender projections which were the first removed. Holes had to be drilled for the explosives in attacking the broader and flatter portions of the reefs. General Newton had originally proposed to work the drills from staging; but the prospect of injury to the staging from drifting vessels led to the construction, instead, of a very strong timber steam scow,[2] capable of withstanding collisions, a necessary precaution, as in one year sixteen vessels collided with the scow with such force as to sink. The scow was provided with apparatus for working the drills, and built with a well in the centre, 32 feet in diameter, through which twenty-one drills could be worked; and an iron hemispherical dome, 30 feet in diameter, was lowered on to the rock, through the well, for the purpose of protecting the men when working in a strong current. The scow was first used in the winter of 1870-71. The cost per cubic yard of rock drilled, blasted, and removed, was £3 17*s.* at Way's Reef, and £4 12*s.* 6*d.* at Heel Tap Rock.

The removal of Hallett's Point was determined on in 1869; and eventually the remainder of General Newton's scheme was approved, consisting in the union of the middle and east channels by removing

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[1] "Report from the Secretary of State for War," (United States) 1868, part ii., p. 730.

[2] Minutes of Proceedings Inst. C.E., vol. lviii., p. 385; and "Scientific American," July 19, 1879.

the Gridiron, Flood, and other rocks of the Middle Reef to a depth of 26 feet at mean low-water, (Plate 6, Fig. 4), so as to increase the width of channel from 600 to 1,200 feet, obliterate these dangers to navigation, and reduce the current to 4 knots; the removal also of the Heel Tap and other minor rocks to the 26-foot depth, and the construction of sea walls on the Hog's Back and the Great and Little Mill Rocks formed part of the scheme. The cost of lowering these rocks by surface drilling, blasting, and removing débris, was estimated in 1867 at £9 4*s*. 6*d*. per cubic yard, giving a total cost of £1,810,970. This method of execution, however, whilst suitable for small detached reefs, would have been slow and costly for the large areas of Hallett's Reef and Flood Rock. Accordingly the plan of sinking a shaft in the reef, driving a network of galleries under the rock throughout the area within the 26-foot contour, leaving pillars for supporting the roof, and finally shattering the roof and pillars by the simultaneous explosion of a number of cartridges placed in them, was adopted for Hallett's Point and Middle Reef, the débris of rock being subsequently removed by grapple dredgers down to the requisite depth. (Plate 6, Figs. 1, 2, 3, 5, and 6.) By this modification, the estimated average cost per cubic yard of rock removed was reduced to between 62*s*. and 93*s*., and the total estimate to £977,050, or little over half the original estimate. The period required for the work was reckoned at ten years.

Hallett's Point.—Work was begun at Hallett's Point in 1869 by enclosing a portion of the reef, which was dry at low-water, within a strong cofferdam connected with the shore at both ends (Plate 6, Fig. 2); and the sinking of a shaft within the protection of the cofferdam was commenced the same year; but the completion of the shaft, to a depth of 33 feet below mean low-water, was delayed till late in 1870, owing to want of funds. Tunnels were then driven radiating from the shaft, intermediate galleries were formed in the wider intervals, and cross galleries were constructed as shown on the plan (Plate 6, Fig. 2). The galleries extended under the whole of the reef within the 26-foot contour, which stretched out 325 feet from the shore and covered an area of 3 acres their total length was 7,425 feet, and the roof was supported by one hundred and seventy-two pillars. The drilling was at first done by hand; but steam drills were introduced in 1871. The greatest rate of progress occurred in 1872–73, during which year 2,731 feet of galleries were driven, and 9,554 cubic yards of rock were removed. The progress, however, was necessarily slow, as shallow holes and small charges had to be used, owing to the small

thickness of rock above the workmen, and owing to the small adhesion between the dipping strata of rock, consisting of foliated hornblende gneiss with numerous veins of quartz. Moreover the work was delayed by the insufficiency of the yearly appropriations granted by Congress; so that the work of preparation for the explosion, which might have been completed in four years, extended over six years and ten months. The galleries were completed in June 1875, the excavations amounting to 49,480 cubic yards; and the drilling of holes for inserting the cartridges in the roof and piers was then commenced. The roof was left 20 feet thick in places where the rock was unsound, and elsewhere varied from 6 to 15 feet; whilst the columns averaged 10 feet in thickness, and were from 8 to 22 feet high. The holes were placed from 6 to 10 feet apart; 5,375 3-inch holes were drilled in the roof, and 1,080 3-inch, and 286 2-inch holes in the piers; the 3-inch holes averaged 8¾ feet in length, and the 2-inch holes 6⅝ feet: they were completed in March 1876.

Experiments during the progress of the work showed that as much rock could be broken with 10 ounces of rendrock or vulcan powder as with 8 ounces of nitroglycerine, whilst their cost was less than half that of nitroglycerine; and also the use of the pure liquid explosive was less convenient than its solid compounds. Accordingly dynamite, rendrock, and vulcan powder were used in the cartridges for the final explosion. Altogether, 9,127 lbs. of rendrock, 11,853 lbs. of vulcan powder, and 28,935 lbs. of dynamite, giving a total of 49,915 lbs. of explosives, were employed for shattering the 63,135 cubic yards of rock contained in the roof and piers.

As the reef was near inhabited buildings, it was important that the shock caused by the explosion should be as small as possible. It was estimated that the shock transmitted through the roof and piers to the shore would be mainly due to the charges required for their disruption, and that the effect of the additional charges for breaking up the rock might be neglected; and that by keeping down the amount of the individual charges, and giving each their full proportion of useful work, the shock would be immaterial. In order also to prevent a concentric explosion, due to the convergence of the galleries towards the shore, the charges were increased towards the outer zones, giving immediate vent through the roof, and causing a somewhat dispersive explosion which threw some of the débris beyond the reef. On the average, 0·97 lb. of explosive was required to dislodge a cubic yard of rock in enlargements, from which the formula

$C = 0 \cdot 038 L^3$ was obtained, giving the charge C of explosive in lbs. for the holes in the roof, where L is the line of least resistance in feet. The charges for the holes above the piers were calculated by the formula $C = n L^3$, where n was made successively 0·038, 0·05, and 0·06 from the shaft outwards.

The explosives were placed in tin cartridge cases, varying in diameter from $1\frac{3}{8}$ to $2\frac{1}{8}$ inches to suit the tapering holes; and 4,427 holes were charged with 13,596 cartridges, mostly 22 inches long. The priming charges of $\frac{3}{4}$ lb. were next inserted, placed in brass tubes and containing a detonating fuse of 20 grains of fulminate of mercury. The firing was effected by means of 23 zinc and carbon batteries, each of which served for 160 mines divided into eight groups of twenty each. General Newton describes in detail, in his Report of December 1876, the method he adopted for each set of 160 mines, to ensure the simultaneous discharge of the whole system.[1] The lead-wires of each group were connected with one pole of the battery, and the other pole was attached to a brass pin; whilst the return-wires were connected with a brass cup containing mercury. The twenty-three brass pins of each set protruded through a wooden disk suspended by a cord over a set of the mercury-cups. The cord was attached to a dynamite cartridge which, when fired by electricity from the shore, severed the cord, causing the pins to fall into the cups, and thus completed the circuit for all the batteries simultaneously, which, by aid of a small platinum wire placed in each detonator, exploded the mines. The actual number of mines fired by the batteries was 3,640, as the current failed for two groups at the last test, raising the number of unconnected mines, exploded merely by concussion, to 822.

The galleries and shaft were flooded by means of a 12-inch siphon on September 23rd, 1876, and the explosion was effected on the 24th. Spray, mingled with vapour and gases, rose 123 feet at the highest point; but the volume of water raised was small, no windows were broken, and the transmitted land-tremor was slight. The débris of the 63,135 cubic yards of solid rock shattered by the explosion measured 87,000 cubic yards. The proposed plan of excavating a receptacle large enough to receive the whole of the débris, which was partially carried out at Blossom Rock, would have involved the removal of all the piers, replacing them by more slender supports, and the formation of a cavity having a volume $1\frac{1}{2}$ times that of the solid contents of the roof; and it was considered

[1] Report of the Chief of Engineers (U.S.A.) for 1877, part i., p. 237.

both safer and more economical to remove the débris, down to the depth of 26 feet, by grapple dredgers. As only blocks of 5 tons could be easily raised, and blocks exceeding 10 tons could only be lifted under favourable conditions, a good deal of the rock had to be reduced in size by surface blasting, increasing the cost from 9*s.* 6*d.* to 14*s.* per ton. The removal of the débris, amounting to 90,588 tons (equal to 45,294 cubic yards), was completed in March 1882, having cost on the average 11*s.* 6*d.* per ton. The expenditure on the galleries and the explosion was £198,355; and the cost of removing the débris was £52,065; so that the total cost of the removal of Hallett's Point amounted to £250,420.

Middle Reef.—The success of the system adopted at Hallett's Point was so fully assured in 1874, that General Newton urged the commencement of a similar work for lowering the Middle Reef. This Reef, frequently termed the Flood Rock, which formed its most prominent excrescence and in which the shafts were sunk, contained also other projecting rocks called the Gridiron, Hen and Chickens, and Negro Heads, and covered an area of 9 acres above the 26-foot contour (Plate 6, Fig. 1.). Work was commenced in June 1875 by sinking two shafts 65 feet apart, the larger shaft being made 10 feet by 20 feet, and carried down 60 feet below mean low-water, and the smaller shaft 12 feet square. A series of parallel galleries were then driven, with other galleries at right angles, under the whole area to be lowered (Plate 6, Figs. 5 and 6). The work was carried on irregularly owing to deficiencies in the appropriations granted: the greatest advance of the galleries was accomplished in 1880–81, amounting to 7,312 feet; and the maximum excavation, of 21,870 cubic yards, in 1881–82; whilst in 1877–78 the works were suspended, and in 1883–84 the work was almost wholly confined to pumping to keep the galleries from being flooded. As the surface of Flood Rock above water was small, the materials from the earlier excavations were deposited between it and the Gridiron, providing an area of 2,600 square yards for the erection of the machinery. The total length of the galleries was 21,669 feet; they averaged 10 feet by 10 feet in section, but varied in places from 4 to 33 feet in height. The roof, from 10 to 20 feet thick, and averaging 18·8 feet, owing to the risk of an inrush of water if it had been made thinner, was supported by 467 pillars about 15 feet square and 25 feet apart. The amount of rock excavated was 80,232 cubic yards, requiring 2·3 lbs. of explosive and 11·97 feet of drilling for each cubic yard, owing to the great caution needed to avoid breaking into large seams in the rock; whilst the contents of the roof and pillars to be shattered, to a

depth of 30 feet, amounted to 270,717 cubic yards. The galleries were not completed till 1884-85, being delayed by want of funds, and by the uncovering of a seam near the north end, which discharged large quantities of water. One seam encountered was 10 inches wide and 100 feet long; and another, from 1 to 4 inches wide, extended right across the reef, over 400 feet in length; they were filled up with Portland cement as they were opened out.

The drilling of the holes for the final explosion was commenced in May 1882. The holes had a diameter of about 3 inches, and averaged 9 feet in depth; 772 holes were drilled in the pillars, extending down to 33 feet below mean low-water, and 11,789 holes in the roof, being placed about 5 feet apart in the pillars and 4 feet in the roof, at angles respectively of 45° and 60°. The cost of preparing the mine for the reception of the final charge, per cubic yard of rock eventually broken up, was only 11*s.* 2*d.*, as compared with 33*s.* at Hallett's Point.

The charging of the holes was commenced at the end of July 1885. Rackarock, composed of seventy-nine parts of potassium chlorate and twenty-one parts of nitrobenzol, was used instead of dynamite for the bulk of the cartridges, as its ingredients, being harmless previous to their admixture, could be stored in large quantities, and conveyed, without danger, to Great Mill Rock where the mixing was done.[1] The great value of this kind of explosive, composed of a solid and a liquid, consists in the facility and safety with which the mixture of the ingredients is effected by the simple absorption of the liquid by the solid; whereas two solids, equally harmless apart, could not be thoroughly mixed, on the spot, in large quantities to form a similar explosive, without such great risk as practically to prohibit the adoption of the process. Rackarock, moreover, is an inert explosive, and whilst costing little more than half as much as dynamite, it possesses somewhat greater efficiency under water. The holes were nearly

[1] This explosive was invented in 1870 by Dr. H. Sprengel, F.R.S., a German chemist resident in London, who first suggested and investigated a series of explosives of this class ("Chemical News," vol. lii., p. 215). He patented this and other safety-explosives of the same type in England on April 6th and October 5th, 1871; and described them fully in the "Journal of the Chemical Society," 1873, under the title, "On a new class of explosives which are non-explosive during their manufacture, storage and transport." Mr. S. R. Divine, of New York, claims to have invented this explosive about the same time ("Chemical News," vol. lii., pp. 271 and 295); but he appears not to have published or patented it till 1880. (See Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 351; and "The Hell-Gate Explosion and so-called 'Rackarock'," by H. Sprengel. London. E. and F. N. Spon. 1886.)

filled with 6-lb. rackarock cartridges, 24 inches long and 2¼ inches in diameter, the cases being made of copper 0·005 inch thick (Plate 6, Fig. 9). An exploder was inserted in the outer end of each cartridge, consisting of a tube containing dynamite, in which was another tube filled with 30 grains of fulminate of mercury (Fig. 7). A 3-lb. dynamite cartridge, 15 inches long and 2¼ inches in diameter (Fig. 10), was last inserted in each hole; and its end, containing a 30-grain fulminate exploder, projected about 6 inches out of the hole (Fig. 12). Four brass wires were fastened at the end of each cartridge, which projecting outwards pressed against the side of the hole and kept the cartridge in its place. Each cartridge, when filled, had its lid soldered on by an alloy whose melting point was 160° Fahrenheit.

The 42,500 cartridges placed in the holes, containing 240,399 lbs. of rackarock and 42,331 lbs. of dynamite, were exploded by sympathy, being unconnected with the batteries used for firing the mine. The primary explosion was effected by five hundred and ninety-one exploders placed along the galleries at intervals of 25 feet, as it had been proved by experiment that a 10-lb. charge of dynamite would discharge with certainty, under water, another charge of dynamite in a thin elastic case at a distance of 27 feet. The exploder consisted of a brass cylinder, 8 inches long and 2 inches in diameter (Plate 6, Fig. 11), filled loosely with ½ lb. of dynamite so as not to be affected if water should get in, into which the fuse was inserted, consisting of a copper tube containing 30 grains of fulminate of mercury, in which a second tube fitted holding the two conducting wires, which were held in place by a packing of sulphur, and were connected at their ends by a small platinum wire inserted in the fulminate (Fig. 8). The brass cartridge was tied on to two thin copper cartridges (24 inches by 2¼ inches), packed tight with 10 lbs. of dynamite so as to explode by sympathy if the fuse should fail; and these cartridges were lashed on a beam fixed across the gallery at a height of from 3 to 12 feet above the floor according to the height of the gallery (Plate 6, Fig. 12). The exploders were arranged in twenty-one circuits of twenty-five each, and three circuits of twenty-two each; and adjacent exploders were placed on different circuits, so that they might explode by sympathy, if one of the circuits failed. All the circuits were simultaneously closed by the arrangement shown on Plate 6, Fig. 13. The carbon, zinc, and potassium bichromate battery comprised sixty cells, all coupled in one series, with two large cups of mercury forming the poles, into one of which the twenty-four lead-wires dipped. A third cup received the twenty-four return-wires, between

which and the second cup, forming the negative pole, the circuit closer was placed. The circuit closer consisted of a strong iron vessel containing mercury, in which stood a thin glass tumbler, also containing mercury; and the mercury in the vessel was connected with the negative pole, while the mercury in the tumbler was connected with the cup into which the return wires dipped, so that the glass of the tumbler alone prevented the completion of the circuits. A ¼-inch iron rod, with a disk on the top, rested vertically with its point on the bottom of the tumbler. A 30-grain fuse was placed on the disk; and the firing of this fuse, by wires leading to a battery at Astoria, drove down the rod and, breaking the tumbler, closed the circuits.[1] An automatic arrangement was devised by Lieutenant Derby for firing the mine in the event of failure of the connection with Astoria, by which a slow flow of mercury into a cup connected with one pole would have raised the level of the mercury, in fifteen minutes, so as to come in contact with a suspended pin connected with the other pole, and thus have closed the circuit; but eventually this provision was dispensed with.

The flooding of the galleries was commenced by two siphons on October 9th; and the explosion was successfully effected at 11.13 A.M. on October 10th, 1885. The water rose in mass over the site of the reef, the spray shooting up in peaks at some points between 100 and 200 feet in height. An idea may be formed of the width and length of this action from the illustrations drawn from photographic views taken from Blackwell's Island and Astoria (Plate 6, Figs. 14 and 15). No loud report or great shock occurred; and the damage was confined to the breaking of a few panes of glass, the falling of some loose ceilings, and the shaking off of some loose bricks from a chimney at Astoria. A slight vibration was observed at Cambridge, Mass.; and vibrations were recorded at Harvard College, 185 miles distant, two hundred seconds after the explosion, indicating a rate of transmission of 4,900 feet per second. The cost of the final explosion was £22,190, which compares extremely favourably with the expenditure of £16,894 at Hallett's Point, considering that the blast was more than five times larger: this saving was due both to the employment of rackarock, and to the sympathetic method of explosion adopted. The total cost of breaking up the Middle Reef, per cubic yard of rock mined and shattered, was 12*s.* 5½*d.*, making the total expenditure £218,612 hitherto. The rock shattered by the final explosion, however, has

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[1] "The Sanitary Engineer," New York, December 3rd, 1885, p. 10.

still to be dredged away before the contemplated improvement in the channel can be fully realized. The first contract, for the removal of 30,000 tons (15,000 cubic yards), has been let for 13*s.* 3½*d.* per ton; and it is estimated that the whole could be removed in three years' time if adequate appropriations are granted.

The success of the explosion at Flood Rock was complete, and the advantage of the system has been fully established; but it has been suggested that the cost of the work of mining under Middle Reef was greater than at Hallett's Point; that a portion of the final explosion was of the second order, as indicated by the coloured fumes observed; and that the rock has not been sufficiently broken up.[1] The first objection is at variance with the official figures given above. With regard to the second objection, Lieutenant Derby states that he has often observed fumes in exploding dynamite or rackarock under water; and that if not naturally a product of an explosion of the first order, they are probably due to the action of these products, at a high temperature, on the finely-divided water. The price of the initial dredging seems to indicate that the rock has not been so much broken up as at Hallett's Point; but, on the other hand, Lieutenant Derby considers that the top layer is the most difficult to remove. Moreover, though the greater thickness of roof at Flood Rock has probably caused a larger proportion of explosive, per cubic yard of rock, than at Hallett's Point (1·04 lbs. as compared with 0·79 lb.), to produce a less thorough breaking-up of the rock, it is likely that prudential considerations led General Newton to limit the charge in the case of an explosion of unprecedented magnitude, preferring an increased cost in subsequent dredging to the risk that might be incurred in fully breaking up the rock by a greater explosion.

The total estimated cost of the Hell Gate Improvement Works, including also the expenditure incurred in lowering Diamond and Coenties reefs in New York harbour, and a reef near the North Brothers in Long Island Sound, amounted to £1,070,650, of which £736,700 had been appropriated at the end of June, 1884, leaving £333,950 at that date still to be expended.[2] The works, when

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[1] "The Engineering and Mining Journal," New York, October 24, 1885, pp. 288–291.

[2] The Author has obtained many details about the Hell Gate Improvement Works from General Newton's yearly reports from 1867 to 1884, published in the Reports of the Chief of Engineers (U.S.A.); and he has gathered several particulars about the Flood Rock, or Middle Reef, works from an article by Lieut. G. McC. Derby, engineer officer in charge of the works, published in the "Sanitary Engineer" (New York), Dec. 3, 1885. He is also indebted to the

fully completed by the removal of the débris on the Middle Reef, will afford New York an excellent direct channel to the ocean through Long Island Sound.

"Scientific American," Oct. 10, 1885, for some details about the cartridges used at Flood Rock, and to Mr. T. J. Long, M. Am. Soc. C.E., for photographs of the explosion. Accounts and illustrations of the works will also be found in the "Engineering and Mining Journal," Sept. 30, 1876, and Oct. 24, 1885; the "Scientific American," July 25, and Oct. 17, 1885; "Engineering News," Oct. 17, 1885; the "New York Herald," Oct. 11, 1885; the "Daily Graphic," Oct. 10, 1885; and in "Engineering," vol. xxii., p. 346, and vol. xl., p. 143; and the "Engineer," vol. xlii., p. 217.

(*Paper No. 2152.*)

"The Granada Earthquake of 25 December, 1884."

By Edward J. T. Manby, M. Inst. C.E.

Some description of this earthquake, one of the most violent and destructive of modern times, may perhaps be considered worthy of a place in the Minutes, at a time when members of the profession are earnestly studying the means of minimizing the effects of similar disasters by suitable methods of building. Even in the midst of the wholesale ruin wrought by the shock in the provinces of Granada and Malaga, there are signs that a more judicious selection of the sites of towns and more substantial buildings might have lessened the destruction to a very considerable extent.

The area over which the shock was plainly felt measures about 170,000 square miles; but the earthwave affected delicate instruments far beyond those limits, since it was recorded by the seismographs of Rome, Velletri and Moncalieri, and caused perceptible disturbance in astronomical instruments at the Brussels Observatory.

The first and strongest shock, which did nearly all the work of destruction, occurred about nine o'clock in the evening of the 25th of December, 1884. It has been found impossible to determine the exact time with any approach to accuracy, and this of course attaches great uncertainty to all calculations regarding the velocity of the earthwave. In all the published Spanish reports it is stated that it has been impossible to determine this important point. The French Commission of the Académie des Sciences has somewhat boldly set down the horizontal velocity of the wave proceeding from the epicentrum at about 1 mile per second, but this calculation rests upon very doubtful data.

The first shock was followed in the course of the night by many other shocks, which had little effect beyond increasing, in a comparatively small measure, the damage done. Minor shocks and tremors continued to prevail almost daily until May, 1885.

The epicentrum, or area within which the destructive effects of the earthquake reached their maximum intensity, and which may be classified under the last number of Rossi's scale—(10. Great disasters, general destruction of edifices, opening of chasms, fall

of rocks, &c.)—extended over about 200 square miles, being about 25 miles long by 8 miles broad, and lying S.E. to N.W.

The loss of life and personal injury amounted to seven hundred and forty-five dead and one thousand four hundred and eighty-five wounded, and the damage to buildings to four thousand four hundred houses totally destroyed, six thousand three hundred and twenty partially destroyed or injured beyond repair, and eight thousand six hundred seriously injured but not requiring total reconstruction. This havoc was distributed over one hundred and eight towns and villages situated in the provinces of Granada and Malaga, but the largest share of the disaster was borne by the town of Alhama, where three hundred and seven people were killed and five hundred and two wounded, and over one thousand houses were totally destroyed.

Within this area, the direction of the shock was principally vertical. The cracks in the walls were symmetrical to the plumb-line; tiles were broken upon the roofs, and flooring boards were burst upwards. Heavy pieces of rock were split and hurled down from the hills; in many places the disturbance in the solid rock on the hillsides and river-banks bore the appearance of the explosion of some gigantic mine; hot-springs appeared in different places, some of which continue to run, and the level of the water in all the wells of the district seems to have been permanently altered. Innumerable chasms and cracks were opened throughout the whole of the district, some continuously traceable over a length of 4 miles.

One of the most appalling effects of the shock was the ruin of Guaro farm, which was swallowed up by the earth. The ground was completely broken up over a surface of 12 acres round the farm, some of the crevasses measuring 35 feet in breadth and 160 in depth. Portions of the house and of the paved threshing-floor adjacent to it were carried to a considerable distance from the spot as if by an explosion, but the greater part of the building disappeared underground.

With regard to the cause of the earthquake the usual uncertainty prevails, and many conflicting theories have been put forward. The report of the Spanish Commission attributes an entirely local origin to the catastrophe, based upon the following facts:—

Within the limits of the epicentrum there exists an extensive basin of porous rock without any superficial outlet, called the Valley of Zafarraya. All the rainfall of this region makes its way down through cracks and caverns to the underside of the jurassic limestone which forms the Loja chain of mountains, and apparently

finds an outlet in numerous springs situated at a level about 1,600 feet below the valley, some of these near the city of Loja, and others in the northern part of the province of Malaga. In very rainy years this outlet proves insufficient, and serious inundations occur in the valley. The Commission assumes the existence of an immense underground reservoir, or communicating reservoirs of water, in this region, and supposes this vast fluid body to have been set into a state of violent disturbance by a sudden increase of temperature due to pressure, friction and electro-telluric forces—a theory which has found great acceptance of late years among a number of Italian scientists. The villages situated in and around this peculiar district have certainly suffered most severely. In the village of Zafarraya nearly all the houses were destroyed; one wall of the mayor's house was literally thrown out of the ground with its foundations adhering to it, leaving the trench, 18 inches deep, perfectly clear of masonry. Furthermore some accounts tend to show (though the evidence upon this point is not absolutely reliable) that the Valley of Zafarraya was the epicentrum, and that many of the minor shocks seemed to radiate from it in all directions.

The Commission of the Académie des Sciences rejects the above theory, and considers that such a cause would be inadequate to account for the vast amount of energy developed and transmitted to such great distances. It prefers to attribute the earthquake to the action of igneous matter seeking an outlet. In support of this theory, the French Commission has, by novel methods of calculation, located the probable centre of explosion, or point of application of the volcanic force, at a spot about 7 miles below ground. It is but fair to add that the Spanish Commission, in support of its theory, and by another system of calculation, has assigned a depth of 2½ miles to the same point.

A suggestion may perhaps be ventured, that whatever the essential cause of the energy developed in the bowels of the earth, whether volcanic, chemical, or electrical, the presence of a large underground body of water, extending through fissures and caverns to a depth of possibly several miles, would be highly instrumental, on account of the incompressibility of the fluid, in transmitting to the earth's surface any force applied with explosive velocity at any point of the liquid mass. At all events, its transmissive and distributive action would be immensely greater than that of the neighbouring masses of heterogeneous, stratified, and more or less compressible rock. It might therefore appear not altogether unlikely that a sudden outbreak of volcanic or chemical energy,

possibly delivered in the form of gaseous or liquid matter, at an enormous temperature, through a small channel or fissure at the bottom of this gigantic hydraulic press, should have been transmitted to the extreme points of the fluid mass, with sufficient force to break up the superincumbent and surrounding rocks. It appears that, in masses of solid and fluid matter co-existing at great depths, and consequently under enormous pressure, a very slight but sudden variation of temperature in a small portion of the liquid body might suffice to destroy a state of equilibrium, and send enormous disturbance throughout its whole mass. The secondary effect of this momentary change of the normal pressures at great depths would also be enormous, and, acting through immense masses of rock, might be not unreasonably considered sufficient to propagate surface undulations to a great distance. Mr. Milne's valuable experiments[1] show that the undulations away from the epicentrum are almost purely superficial, and do not affect the soil beyond a few feet in depth; it is therefore evident that their production and transmission do not really absorb such great initial energy as has been hitherto thought necessary to account for their distant travel.

The disaster of the Guaro farm brings to one's mind the idea of the bursting of a hydraulic press. There was a small spring in the neighbourhood which disappeared with all its surroundings, and a vast amount of mud was found washed down the neighbouring valley after the earthquake. It is conjectured that the farm stood over caverns in the limestone full of water, which burst out under the influence of the shock.

It is tolerably evident that the widespread havoc caused by the earthquake might have been much less, had the sites of many of the villages been better chosen, and had the houses been more strongly built. The Spanish official report says: "The situation of the greater number of the ruined towns and villages is such, that it appears as if they had been purposely located on the very spots where the consequences of a local earthquake were likely to prove most terrible; the principal reason for this being that the founders of these towns, in times of constant strife and warfare, sought with preference situations difficult of access and easy of defence, locating them frequently upon small plains at the foot of a precipice; that is to say, precisely over a geological fault, where they usually found besides, the additional advantage of good soil for agriculture, composed of detritus of different formations."

[1] Minutes of Proceedings Inst. C.E. vol. lxxxiii. p. 279.

Some other villages were built upon loose formations of considerable dip, which were continually slipping away in ordinary times towards the ravines or watercourses, as was the case in the village of Albuñuelas. In this place and its neighbourhood landslips were of continual occurrence; to such an extent that the priest residing there, who lost his life in the earthquake, had written a fortnight previously to his colleague in Durcal (a village a few miles lower down the valley): "At the rate the ground is moving, we hope soon to be with you." The formation at Albuñuelas is coarse pliocene limestone resting on a very inclined bed of clay.

The building in all the ruined villages was generally of the very worst description. The poorer houses consisted of boulders laid in mud, and the better ones of half-baked bricks and plaster. Nothing was done to bond the walls, or tie the structure together by properly secured timbers. In all places where the ground itself has not been actually broken up by the earthquake, the few really well-built houses that existed have withstood the shock with comparatively little damage, and in all cases without loss of life to the inmates.

The recommendations contained in the Spanish official report with regard to the reconstruction of the towns are the following:—

(1.) That the streets should cross at right angles, and lie diagonally to the direction of the geological faults.

(2.) That their width should never be less than double the maximum height allowed for the buildings.

(3.) That the houses should not have more than one story.

(4.) That materials and building should be of unexceptionable quality.

(5.) That seismological observatories should be established all over the district.

It is to be regretted that most of these sweeping reforms are being but imperfectly carried out. The ground is generally of so little value in that region that the second and third orders might have been universally enforced without much difficulty, and would certainly have constituted an important element of security against future disasters.

Some of the general advice contained in Mr. Milne's Paper, "On Construction in Earthquake Countries," would undoubtedly be suitable to the provinces of Malaga and Granada. However, the Tôkiô earthquakes seem to consist almost exclusively of the horizontal component of the shock, and the fact that the disturbance is confined almost to the very surface of the earth, would seem to

indicate that the epicentrum must be a good distance off. In the Granada earthquake almost all the damage was done by absolute upheaval. In places where mere horizontal motion was felt, the damage was insignificant. As far as one can judge from somewhat confused data, the velocity of the earthwave proceeding from the epicentrum was relatively small, and the undulation was not subject to such rapid changes of direction or intensity as to render it destructive.

(*Paper No. 2110.*)

"The Design and Stability of Masonry Dams."

By Walter Bulkeley Coventry, M. Inst. C.E.

This Paper is founded on a collection of notes made by the Author whilst recently engaged in designing some masonry dams for the Rio Tinto Mining Company in Spain.

The subject has been divided into two parts. (1) The Design, and (2) the Calculations of Stability. This latter part of the subject is a comparatively simple matter, and by means of the equilibrium-polygon of graphic statics the conditions of stability of any given profile are easily ascertained.

Owing to the indeterminate nature of the problem, it seems impossible to construct a general formula for calculating the dimensions of a dam, and the method usually followed consists in assuming an approximate profile, and then testing its stability by a graphic resolution of forces. If found defective the profile is altered, and the graphic process repeated until a sufficiently exact result is obtained. In large dams a continued repetition of trial alterations becomes very troublesome, and in order to avoid this difficulty the Author devised the method given in Part I of this Paper, by means of which a profile can be calculated with considerable accuracy. The profile thus obtained may then be tested by the graphic process given in Part II, when it will be found that if any alteration is required it will be only in the lower portion of very high dams.

In what follows, the two faces of the dam will be called respectively the "inner face" and the "outer face"—the "inner face" being that against which the water rests. The inner face will for convenience sometimes be called the "back" of the dam.

I.

There are two conditions of stability upon which the design of a dam must be based.

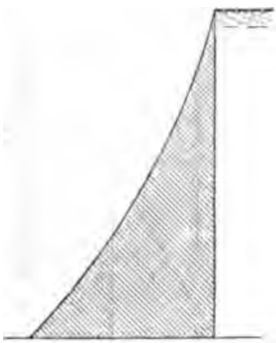
(1) The resultant of all the forces acting at any horizontal section must fall within the middle third of the thickness of the dam.

(2) The stresses in the faces of the dam must not exceed the safe limit.

These two conditions must be satisfied for the extreme cases of reservoir full, and reservoir empty.

Condition (1) implies that there should be no tensile-stress in the masonry, and this is especially necessary for the full reservoir. Another condition might be added, namely, that at any horizontal section the dam must be safe against sliding, but practically this is always the case when conditions (1) and (2) are satisfied.

FIG. 1.



One of the latest works on the theory of dams is a Paper by Mr. Pelletreau, published in the Annales des Ponts et Chaussées for 1876–77[1], in which a formula is given for the curve of the outer face of the dam with a vertical back, and a thin crest at the water-level (Fig. 1). The profile given by this formula fails in condition (1), and the same objection applies to all similar calculations which are based on condition (2) alone, and in which it is sought to obtain a "profile of equal resistance"—that is, a profile with a constant stress in the faces. Mr. Pelletreau's formula also fails in condition (2), as it does not take into account the effect of the obliquity of the resultant, which has been shown by Mr. Bouvier[2] to be of considerable importance.

In commencing the design of a profile, it is necessary to determine beforehand the width of the top, and its height above water-level. Both these dimensions depend to some extent on local circumstances. As a general rule the Author considers the values given by the following empirical formulas to be sufficient (Fig. 2).

For English feet—

$$x_0 = 4 \cdot 0 + 0 \cdot 07 \text{ H} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$y_0 = 1 \cdot 8 + 0 \cdot 05 \text{ H} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where x_0 is the width of the top of the dam, y_0 the height above water-level, and H the total height of the dam (*i.e.* the greatest depth of water).

[1] 5e série. Tome xii. p. 586; tome xiv. pp. 258, 480. [2] *Ibid.* Tome x. p. 173.

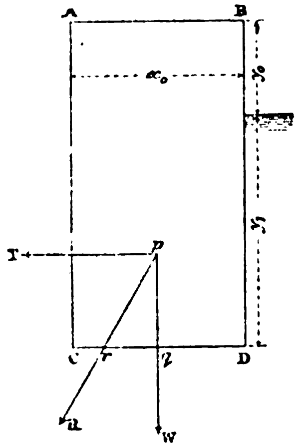
For metres these equations are:—

$$x_0 = 1 \cdot 22 + 0 \cdot 07\,\mathrm{H} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1a)$$

$$y_0 = 0 \cdot 55 + 0 \cdot 05\,\mathrm{H} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2a)$$

In the following calculations the dam will be considered to be a unit in length, measured in a direction perpendicular to the plane of the paper.

Fig. 2.



Let A B C D, Fig. 2, represent a cross-section of the top portion of a dam, x_0 and y_0 having been calculated by equations (1) and (2). It is evident that for a certain depth y_1 below the water, both faces may be vertical, and it would be easy to show that this depth must be determined by condition (1). That is, the resultant of all the forces acting at the section D C must fall within the middle third of D C.

These forces are—

W = the weight of the portion A B C D acting through its centre of gravity, and bisecting D C at q;

T = the horizontal thrust of the water acting at a distance $\frac{y_1}{3}$ above D C.

Calling ϕ the weight of a cubic unit of water, and ϕ' the weight of a cubic unit of masonry—

$$\mathrm{W} = \phi' x_0 (y_0 + y_1),$$

and

$$\mathrm{T} = \frac{\phi y_1^2}{2}.$$

Let R = the resultant of W and T, acting through their intersection p and cutting the base D C at r.

Then

$$\frac{q\,r}{p\,q} = \frac{\mathrm{T}}{\mathrm{W}} = \frac{\phi\,y_1^2}{2\,\phi'\,x_0\,(y_0 + y_1)}$$

$$q\,r = p\,q \cdot \frac{\phi\,y_1^2}{2\,\phi'\,x_0\,(y_0 + y_1)};$$

but $$pq = \frac{y_1}{3}$$

therefore $$q\,r = \frac{\phi}{\phi'} \cdot \frac{y_1^3}{6\,x_0\,(y_0 + y_1)}.$$

By condition (1) $q\,r$ must not exceed $\frac{x_0}{6}$; therefore, putting—

$$\frac{\phi}{\phi'} \cdot \frac{y_1^3}{6\,x_0\,(y_0 + y_1)} = \frac{x_0}{6};$$

and reducing—

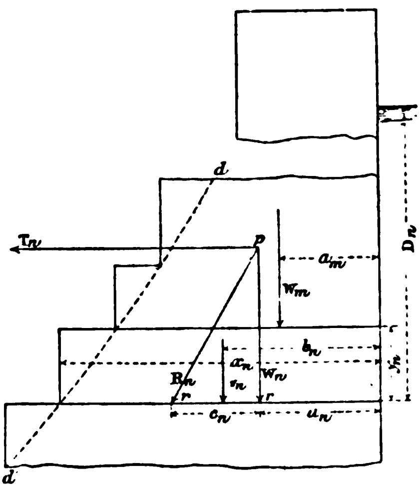
$$y_1^3 - y_1 \frac{\phi'}{\phi} x_0^2 - \frac{\phi'}{\phi} x_0^2\, y_0 = 0.$$

Denoting $\frac{\phi'}{\phi}$ by θ, where θ is the specific gravity of the masonry, the last equation becomes—

$$y_1^3 - y_1\,\theta\,x_0^2 - y_0\,\theta\,x_0^2 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and the value of y_1 which satisfies this equation is the greatest admissible under condition (1).

FIG. 3.



In calculating y_1 it might be advisable to assume the water to be level with the top of the dam, so as to include the effect of a possible rise of water in a flood, or an increase of pressure from waves. In this case by making $y_0 = 0$ equation (3) becomes

$$y_1 = x_0 \sqrt{\theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

Below y_1 the outer face must be curved for some distance down. The back will still be assumed to be vertical, and in order to simplify the calculations the dam will be considered to consist of a series of rectangular layers as shown in Fig. 3.

Let x_n (Fig. 3) be the width of any layer, n and y_n its height. Also let—

W_m = the weight of the dam above the layer n;
a_m = the distance of W_m from the back of the dam;
π_n = the weight of the layer n;
b_n = the distance of π_n from the back of the dam;
W_n = the resultant of W_m and π_n;
a_n = the distance of W_n from the back of the dam;
D_n = the depth from water-level to the base of the layer n;
T_n = the horizontal thrust of the water due to the depth D_n;
R_n = the resultant of W_n and T_n;
ϕ and ϕ' as before are the weights of a cubic unit of water and of masonry respectively.

Let q and r be the points where W_n and R_n cut the base of the layer n, and let the distance $q\,r$ equal c_n.

Taking moments about the back of the dam—

$$W_n\,a_n = W_m\,a_m + \pi_n\,b_n$$

$$a_n = \frac{W_m\,a_m + \pi_n\,b_n}{W_n};$$

but $$\pi_n = \phi'\,x_n\,y_n$$

$$b_n = \frac{x_n}{2};$$

and $$W_n = (W_m + \pi_n) = W_m + \phi'\,x_n\,y_n$$

therefore $$a_n = \tfrac{1}{2}\left[\frac{2\,W_m\,a_m + \phi'\,x_n^2\,y_n}{W_m + \phi'\,x_n\,y_n}\right] \quad . \quad . \quad . \quad (a)$$

In the triangle $p\,q\,r$—

$$\frac{q\,r}{p\,q} = \frac{T_n}{W_n}$$

therefore $$q\,r = p\,q \cdot \frac{T_n}{W_n} = c_n;$$

but $$p\,q = \frac{D_n}{3},$$

and $$T_n = \frac{\phi\,D_n^2}{2};$$

therefore $$c_n = \frac{\phi\,D_n^3}{6\,W_n}$$

$$= \frac{\phi\,D_n^3}{6\,(W_m + \phi'\,x_n\,y_n)} \quad . \quad . \quad . \quad (b)$$

By condition (1) $(a_n + c_n)$ must not exceed $\frac{2}{3} x_n$; therefore, adding (a) and (b), and equating with $\frac{2}{3} x_n$—

$$\frac{3\,(2\,W_m\,a_m + \phi'\,x_n^2\,y_n) + \phi\,D_n^3}{6\,(W_m + \phi'\,x_n\,y_n} = \frac{2\,x_n}{3},$$

and reducing—

$$x_n^2 + \frac{4\,W_m}{\phi'\,y_n} \cdot x_n - \frac{6\,W_m\,a_m + \phi\,D_n^3}{\phi'\,y_n} = 0$$

$$x_n = \sqrt{4\left(\frac{W_m}{\phi'\,y_n}\right)^2 + \frac{6\,W_m\,a_m}{\phi'\,y_n} + \frac{\phi\,D_n^3}{\phi'\,y_n}} - \frac{2\,W_m}{\phi'\,y_n}.$$

Substituting in this equation $A_m\,\phi'$ for W_m, where A_m is the area of the dam above the layer n, and putting as before $\frac{\phi'}{\phi} = \theta$, it becomes—

$$x_n = \sqrt{4\left(\frac{A_m}{y_n}\right)^2 + \frac{6\,A_m\,a_m}{y_n} + \frac{D_n}{\theta\,y_n}} - \frac{2\,A_m}{y_n} \quad . \quad . \quad (4)$$

Making y_n = unity; equation (4) becomes—

$$x_n = \sqrt{4\,A_m^2 + 6\,A_m\,a_m + \frac{D_n^3}{\theta}} - 2\,A_m \quad . \quad . \quad . \quad (4a)$$

Commencing therefore with the top, the thickness of the dam at each successive layer can be calculated by equations (4) or (4 a). This gives a stepped form to the outer face, and by drawing a line as $d\,d'$ (Fig. 3), joining the inner angles of the steps, a practically correct curve is obtained.

There is a peculiarity about the outer face which greatly facilitates its design, namely, that towards the middle of the height its inclination becomes constant; so that when during the process of calculation this is found to occur, the use of equation (4) may be discontinued, and a straight line drawn down to the base of the dam. The vertical back hitherto assumed is only admissible for the full reservoir, as it fails to satisfy condition (1) when the reservoir is empty. This defect may be sufficiently remedied by giving the back a batter of 1 in 20,[1] commencing at the depth y_1. The increased thickness thus given to the dam upsets to some

[1] The straight batter is a close approximation, and nearer the correct form than the concave batter commonly adopted. To comply more nearly with condition (1) the back of the upper portion of the dam should be convex outwards.

extent the previous calculations for the outer face; but the error is small, and on the safe side, as it has the effect of bringing the curve of pressure for the full reservoir further into the middle third of the dam, and also compensates for the error involved in assuming the layers to be rectangular instead of trapezoidal.

To sum up the process of design: Equations (1) and (2) give the thickness of the top of the dam and its height above water-level; equations (3) or (3 a) determine the height of the rectangular portion of the profile, and equations (4) or (4 a) the curve of the outer face. A batter of 1 in 20 is then given to the inner face, and the profile is complete so far as condition (1) is concerned. It must then be tested by the graphic process described further on, and the stresses in the faces calculated, and below the depth at which they are found to exceed the safe limit, the thickness of the dam will have to be increased. One or two trials will generally suffice to determine the required thickness, which, however, may be approximately calculated by the following formulas:—

For the outer face—

$$x = \frac{1 \cdot 07}{\sqrt{2\theta}} \left[y + 0 \cdot 2857 \frac{\phi'}{S} y^2 + 0 \cdot 0808 \left(\frac{\phi'}{S}\right)^2 y^3 + 0 \cdot 0186 \left(\frac{\phi'}{S}\right)^3 y^4 \right] \quad (5)$$

x being the ordinate from the vertical axis to the outer face at any depth y; θ the specific gravity of the masonry; ϕ' the weight of a cubic unit of masonry; and S the stress allowed in the faces of the dam.

For the inner face—

$$z = 0 \cdot 06\, x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where z is the ordinate from the vertical axis to the inner face, and x the corresponding ordinate of the outer face calculated by equation (5).

Equation (5) is simply Mr. Pelletreau's formula multiplied by 1·07, in order to provide for the increased stress due to the obliquity of the resultant, and it may be noted that it is only applicable in the manner mentioned above, that is, for the portion of the outer face of the dam below the level at which the stress in that face is found to exceed the limit S.

The depth at which it becomes necessary to provide for condition (2) depends upon the weight of the masonry, and the permissible stress, and will usually be found to be about $0 \cdot 75 \frac{S}{\phi'}$ for the outer face, and $1 \cdot 10 \frac{S}{\phi'}$ for the inner face.

It may therefore be taken as a general rule that the dimensions of small dams, and of the upper part of large dams, are determined by condition (1) alone; and that unless the height exceeds about $0 \cdot 75 \frac{S}{\phi'}$ condition (2), *i.e.* the question of stress, does not enter into the calculations.

The use of equation (4) is the only part of the process which is at all lengthy; but it is very simple, and the Author thinks will be found to take less time, and give less trouble than a continued repetition of the graphic process, in which the areas and centres of gravity of the different layers into which the profile is divided, have to be re-calculated for each trial alteration. The accumulation of lines on the paper is also a source of much inconvenience.

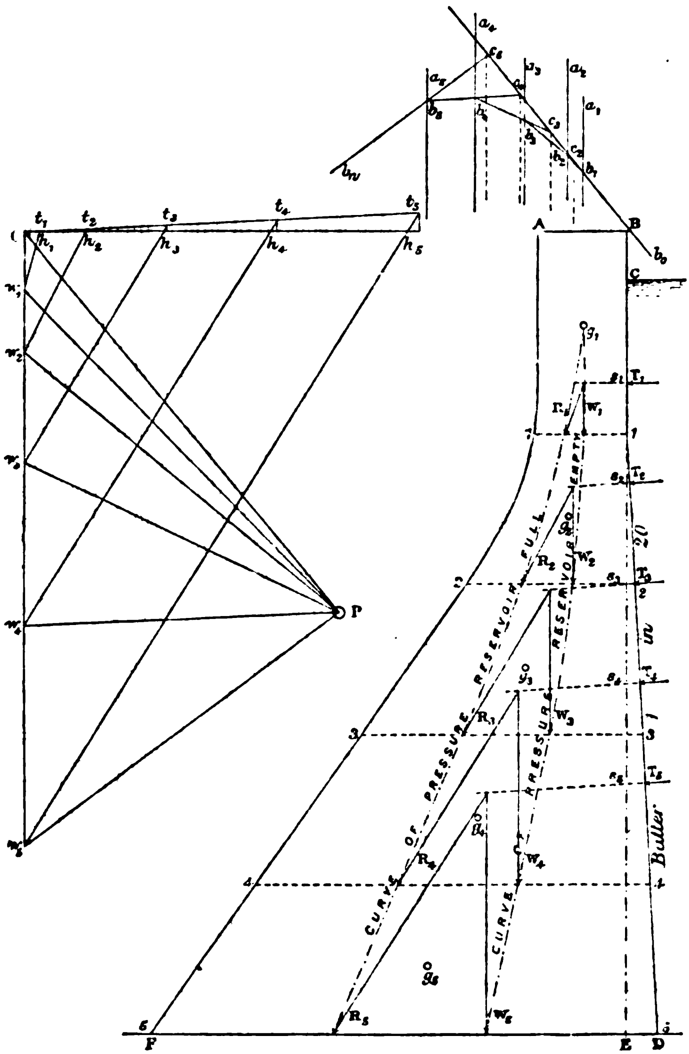
II.

A profile having been drawn in the manner described in Part I, its stability may be tested by the following partly graphic and partly analytical process—

Let the profile A B C D E F (Fig. 4) be divided into a convenient number of zones by the horizontal sections 1—1, 2—2, 3—3, &c.; and let $g_1\ g_2\ g_3$ . . . be the centres of gravity of the corresponding zones. Through $g_1\ g_2\ g_3$ . . . draw the vertical lines $a_1\ b_1$, $a_2\ b_2$, $a_3\ b_3$ . . . On the vertical line of the force-polygon set off to any convenient scale, Ow_1, $w_1\ w_2$, $w_2\ w_3$ . . . . equal to the weights of the zones 1 2 3 . . . ., and from any pole P draw the radial lines PO Pw_1 Pw_2 Pw_3 &c. In the vertical line a_1 take any point b_1, and through it draw $b_0\ b_1$ parallel to PO, and produce it indefinitely. Then draw $b_1\ b_2$ parallel to Pw_1, $b_2\ b_3$ parallel to Pw_2, and so on; the last line ($b_5\ b_6$ in the figure) being parallel to the last radial line of the force-polygon. Produce the sides of the polygon $b_2\ b_3$, $b_3\ b_4$ &c., to their intersections $c_2\ c_3\ c_4$ . . . with $b_0\ b_1$ produced, and through $c_2\ c_3\ c_4$ . . . draw vertical lines (dotted in the figure) down to the corresponding sections of the profile. This determines the positions of the resultant forces $W_1\ W_2\ W_3$ . . ., acting at the different sections when the reservoir is empty. Thus the force W_1 at section 1—1 is equal to the weight of the first zone, and acts through b_1. The force W_2 on section 2—2 is equal to the weights of the first and second zones, and acts through c_2, and so on for the other sections. The line joining the points where $W_1\ W_2\ W_3$, &c., cut the sections 1—1, 2—2, 3—3, &c., is the "curve of pressure" for the empty reservoir.

To find the curve of pressure for the full reservoir, it is only requisite to determine the thrust of the water T, due to the depth

FIG. 4.



Scale of profile = $\frac{1}{150}$.
Scale of forces 150,000 kilos. = 1 inch. $\theta = 2\cdot 3$.

of each section below the water-level, and draw the resultant R of W and T. This may be done in the following manner:—

From the point O in the force-polygon draw a horizontal line, and on it set off (to the same scale as used for the weights) Oh_1 Oh_2 Oh_3 . . ., equal to the horizontal thrusts of the water due to the depths of the sections 1—1, 2—2, 3—3 . . . below the water-level, and through h_1 h_2 h_3 . . . draw the verticals $h_1 t_1$ $h_2 t_2$ $h_3 t_3$ . . . From O draw Ot_1 in a direction perpendicular to the back of the first zone, cutting $h_1 t_1$ at t_1 (in this case Ot_1 is horizontal, and t_1 coincides with h_1). Next draw $t_1 t_2$ perpendicular to the back of the second zone, and cutting $h_2 t_2$ at t_2, and so on. Then Ot_1 Ot_2, &c., give the magnitude and direction of the thrusts T_1 T_2, &c., for the corresponding sections. To find the position of these thrusts set off Cs_1, equal to two-thirds of C1; Cs_2 equal to two-thirds of C2, &c. Project these points horizontally to the back of the dam, and through the points of intersection so obtained draw T_1 parallel to Ot_1; T_2 parallel to Ot_2, &c. Produce T_1 T_2 T_3 to meet W_1 W_2 W_3, and through their intersection draw R_1 parallel to $t_1 w_1$, R_2 parallel to $t_2 w_2$, &c.

The line joining the points of intersection of R_1 R_2 R_3 . . . and the sections 1—1 2—2 3—3 . . . is the curve of pressure for the full reservoir.

It will now be seen whether the curves of pressure fall, as they should do, within the midde third of the thickness of the dam. This is an essential condition for the full reservoir, as any tension in the back of the dam might cause cracks in the mortar through which water would be admitted to the interior of the work. In such a case there would be an internal bursting-pressure which would tend to diminish the stability of the dam. For the empty reservoir, condition (2) is of less importance, and for this reason the method of design given in Part I has been devised in such a manner, that the curve of pressure for the full reservoir shall always be well within the middle third.[1]

It now remains to calculate the stresses in the faces of the dam, for which purpose a general formula may be obtained.

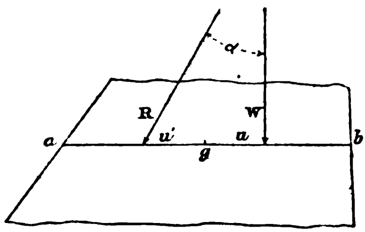
Taking first the case of the empty reservoir, let ab (Fig. 5) be any horizontal section of length $ab = l$, and width unity. Let W be the resultant pressure on ab, acting at a distance u from the

---

[1] In Fig. 4 the curve of pressure for the full reservoir is outside the middle third between sections 1 and 2, but this is only an error in the drawing, the distance between the sections having been taken greater than would be the case in practice, in order to make the diagram more distinct.

centre of gravity g of the section. The force W may be considered as causing in the section $a\,b$ a uniform compressive stress $= \frac{W}{l}$, and in addition to this a bending moment $= W\,u$, which produces compression at the edge nearest W, and a tension of the same amount at the opposite edge. The combined effect of these two stresses is the total stress S in the face of the dam. The stress at a or b, due to the bending moment $W\,u$, is given by the well-known formula $\frac{W\,u}{I} \times \frac{l}{2}$, where I is the moment of inertia of the section. The section being rectangular, $I = \frac{l^3}{12}$. Substituting this value,

FIG. 5.



and taking the algebraical sum of the two stresses, the expression for the stress at a or b becomes—

$$S = \frac{W}{l} \pm \frac{12\,W\,u\,l}{2\,l^3}$$

$$= \frac{W}{l}\left(1 \pm \frac{6\,u}{l}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

With the plus sign this formula gives the stress at the edge nearest W, and with the minus sign the stress at the opposite edge. A minus value of S indicates tension, but this of course only occurs when the resultant force is outside the middle third.

For the full reservoir equation (7) requires a modification. It was formerly the custom, in calculating the stresses due to an oblique force, to consider only the vertical component of that force; but it has been shown by Mr. Bouvier that the stresses calculated in that manner are considerably below their correct value, and that instead of the vertical component, it is the force itself, divided by the cosine of the angle which it makes with the vertical, that must be taken as the effective force. Thus in Fig. 5,

if R is the resultant force acting at the section $a\,b$ when the reservoir is full, u' its distance from the centre of gravity of the section, and a the angle which it makes with the vertical, equation (7) becomes

$$S = \frac{R}{l \cos a}\left(1 \pm \frac{6\,u'}{l}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (7a)$$

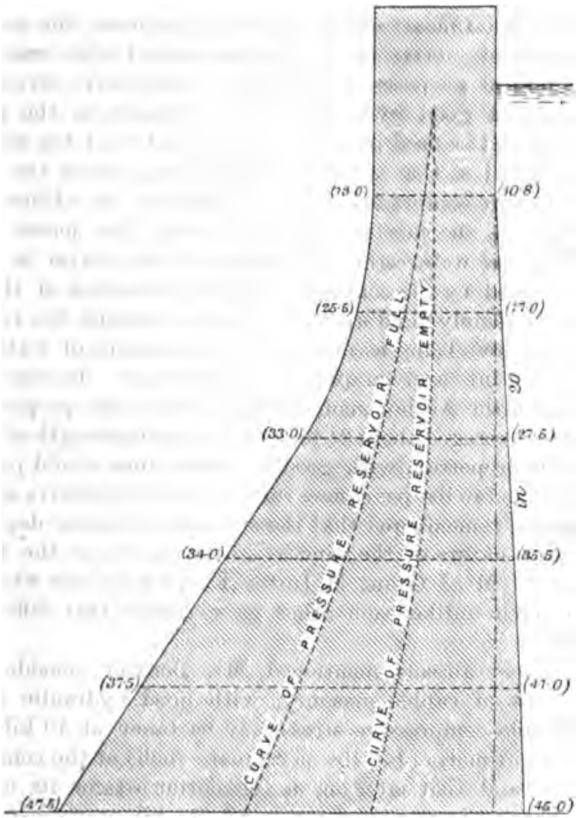
Owing to the difficult nature of the experiment, the compressive strength of mortar cannot be determined with exactitude. For all practical purposes, however, the compressive strength of mortar made of good hydraulic lime or cement, in the proportions that should be used in a dam, may be taken at ten times its tensile strength; so that a factor of safety of $\frac{1}{10}$ gives the simple rule that the safe compressive stress is equal to the ultimate tensile strength of the mortar. In order that the joints of the masonry may be watertight, the quality of the mortar is practically determined by the condition that the interstices of the sand should be completely filled up by the lime or cement, the required proportion of lime being ascertained by the amount of water that can be poured into a given quantity of dry sand. In some experiments which the Author made in this manner, the proportion of sand to water averaged about $2\frac{1}{3}$ to 1. The tensile strength of mortar made in this proportion with good hydraulic lime would probably not be less than 140 lbs. per square inch at the end of twelve months; but it must be remembered that the strength of mortar depends as much on the nature of the sand as on the quality of the lime or cement itself. Mr. J. Grant, M. Inst. C.E., quotes a case where two sands not much unlike each other gave results that differed by 50 per cent.

In the Paper already mentioned, Mr. Bouvier considers that in dams built of rubble masonry, with good hydraulic mortar, the permissible compressive stress may be taken at 10 kilograms per square centimetre (140 lbs. per square inch) at the completion of the work, and that later on, as the mortar attains its ultimate strength, this pressure may be raised to 14 kilograms per square centimetre (200 lbs. per square inch). This may be effected by limiting the depth of water, say for the first twelve or eighteen months, and then allowing it to rise by degrees to its final level.

It has been mentioned that in designing a dam in the manner described in Part I, the curve of pressure for the empty reservoir will sometimes be found to fall outside the middle third of the thickness. In this case the stress calculated by equation 7 will have a minus sign, indicating the tension in the outer face. This tension must be resisted either by the tensile strength of the

mortar, or by the adhesion of the mortar to the stone. Assuming these two resistances to be equal, there would be no danger in allowing a tensile stress in the outer face of the dam equal to one-tenth of the ultimate tensile strength of the mortar.

Fig. 6.



NAYA DAM.

The figures in brackets give the stresses in lbs. per square inch in the outer face for the full reservoir, and in the inner face for the empty reservoir. $\theta = 2 \cdot 6$.

Scale $\frac{1}{1200}$

The specific gravity of rubble masonry is approximately equal to two-thirds of the specific gravity of the stone plus one-third of the specific gravity of the mortar. The quantity of stone required for a rubble-masonry dam may be estimated in the same

way, there being about two-thirds of a cubic yard of solid stone to every cubic yard of masonry.

Fig. 6 is a section of the Naya dam lately built by the Author for the Rio Tinto Mining Company. It affords an illustration of the fact that the stress which the masonry is capable of supporting does nor necessarily influence the design, much less can it be made the sole basis of the calculation. The greatest stress in this dam is 47½ lbs. to the square inch, whilst the mortar (2½ of sand to 1 of Portland cement) is capable of bearing with safety more than three times that amount. The curves of pressure towards the base coincide very nearly with lines limiting the middle third of the section, so that it would be impossible to reduce the area of the profile, and so increase the stresses, without at the same time bringing the curves of pressure outside their proper limits. On the other hand, to have reduced the quantity of cement so as to make its resistance suit the stresses, would have made the mortar porous, which in this case it was important to avoid, as the dam is destined to retain water containing large quantities of sulphuric acid. The joints of the inner face of this dam are pointed with neat cement.

In conclusion the Author would suggest the use of the metre and kilogram as units in designing a dam. The calculations are much easier than when English measures are used.

The Paper is accompanied by several diagrams, from which the Figs. in the text have been prepared.

(*Paper No. 2169.*)

"On the Effects of various kinds of Liquids, Hot and Cold, on Iron, and the best means of Preserving it under such conditions from Corrosion."

By DAVID PHILLIPS, M. Inst. C.E.

THE Author thinks that the results of the experiments which he has been engaged in carrying out during the past eight years, although on a small scale, may prove interesting, and even useful, to engineers.

These experiments consisted of three series, which had for their respective objects to ascertain—

I. The effects on iron of various kinds of liquids, ranging in temperature daily from that due to the atmosphere indoors to the boiling-point, and the best means of preserving it under such conditions from corrosion.

II. The effects on iron of various kinds of cold liquids indoors, and the best means of preserving it under such conditions from corrosion.

III. The effects on iron of small pieces of metals and other substances used by engineers in contact with it, or in its proximity, in cold sea-water.

Prior to these experiments the Author tried the effects on iron, with and without zinc, of several kinds of chemicals mixed in various proportions with fresh water, with the result that he found that the zinc would not act in the absence of the very agents which are known to corrode iron.

Chloride of sodium (common salt), even when twice as much was present as in sea-water, neither acted on the iron, nor assisted the zinc in the least degree; but, in water containing the same proportion of salt and sulphuric acid as the sea, whilst the iron to which no zinc was attached was acted on very injuriously, the colour changing almost immediately and a red oxide forming, that in the same bottle to which zinc was attached was thoroughly protected. With one-half as much salt and sulphuric acid similar results were obtained, except that the unprotected iron suffered less. With one-quarter as much salt and sulphuric acid the protected iron afforded the usual satisfactory results, the unprotected

iron suffering again still less; whilst on the addition of chloride of magnesium, in the proportion also of one-fourth of that contained in sea-water, the protection afforded by the zinc became still more manifest.

The proportion of zinc-surface to iron-surface was very large, namely, as 1 to 16; but the loss of zinc by oxidation was trifling, appearing to be in proportion to the quantity of salts used and the protection afforded to iron.

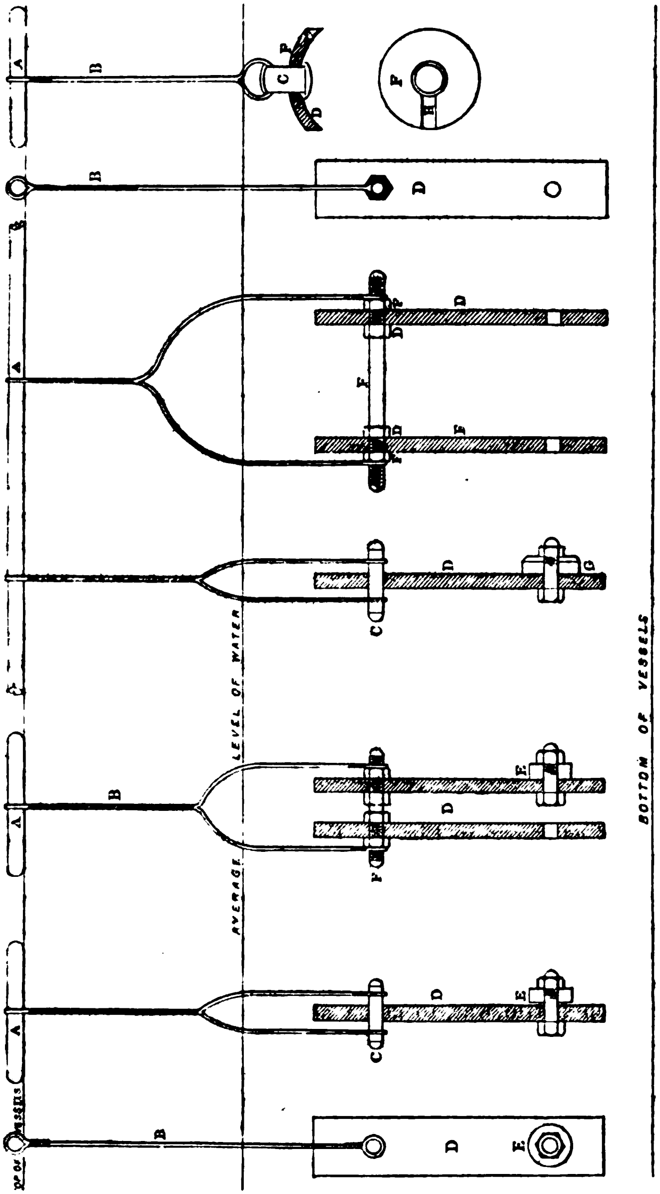
The trials lasted three months, the examinations taking place at intervals of twenty-one days. The water in the boiler was kept at a temperature of from 200° to 212° for about thirteen hours daily, but was allowed to cool down in the early morning.

In Series I. of the principal experiments, the Author had in view four objects:—1. To illustrate the effects of sea- and of fresh water on iron with the losses from evaporation made good by sea- and by fresh water, as the case might be, in small and large proportions; 2. To illustrate the effects of changing the whole of the water at short and at long intervals; 3. To illustrate the protection afforded by zinc under the above specified and other conditions; and 4. To ascertain how bad fresh water could be medicated so as, with the aid of zinc, to preserve land-boilers from corrosion.

The specimens were suspended in glass bottles, containing each a little more than an imperial quart of water, and placed in an open boiler having a cover with openings only sufficiently large for the steam to escape, and for the necks of the bottles, which protruded through it so as to admit of the loss of the liquids in them through evaporation being made good at intervals. The specimens were each of Lowmoor iron, 5 inches by 1 inch by ¼ inch, and were bright originally. They were suspended on glass rods as shown in Fig. 1. Each bottle contained two plates which were suspended separately, except in No. 3 bottle, in which the plates were connected by a copper rod and nuts as shown in Fig. 2. This series lasted twelve months (1878–79), and was under the personal care of the Author.

The Author need not enter minutely into the conditions under which each bottle was, to use a ship-board phrase, "worked," as Table I. in the Appendix, and Figs. 1 and 2 give all the particulars as well as the results. From these it will be seen that hot fresh water acts less injuriously on iron than hot sea-water—a fact which is not new to anyone conversant with the working of boilers; that the smaller the proportion of sea-water, and the less frequently the water, fresh or salt, is changed, the less does the iron suffer from corrosion; that zinc affords the iron no protection in pure

FIG. 1. FIG. 2. FIG. 3. FIG. 4. FIG. 5.



A, wood. B, brass. C, glass. D, iron. E, zinc. F, copper. G, brass, lead, &c., &c. H, copper removed.

fresh water, but in fresh water with one-thirtieth of its volume of sea water added weekly, does afford protection; and that in fresh water mixed with about one-fourth of the proportion of chloride of sodium, sulphuric acid and chloride of magnesium contained in sea-water, zinc properly attached also protects iron, as well as in sea-water; but with this difference, that it is necessary, in order to prevent corrosion, to change the liquids every three months.

Equal protection would have been afforded, no doubt, if the proportion of sulphuric acid, &c., had been considerably reduced, as it will be seen from the Table that the addition of a very limited quantity of sea-water enabled the zinc to act in fresh water of the same temperature.

It will be observed, too, that one of the plates in the boiler, although this was supplied with fresh water, suffered considerably more than any of the rest. This may be taken as confirmatory evidence of the injurious effects on iron of frequently changing the water, either wholly, or by the additions necessary to make up the losses from evaporation, or otherwise. The companion plate, having zinc attached to it, suffered far less, the protection thus afforded being no doubt due to the presence of sea-salts in the water, arising partly from the spilling of small quantities of sea-water when the daily or weekly additions were made, and partly from the occasional boiling over of the liquids in the bottles. Both pieces, too, suffered more at the top than at the bottom ends through the exposure to the atmosphere caused by the water being allowed, occasionally, to get too low.

The slight grooving noticeable in the specimens to which zinc was bolted is similar to the corrosion, more or less severe according to circumstances, which takes place, however good the protection otherwise in boilers similarly protected, that is, when the zinc is in direct contact with the iron. This is due, the Author has no doubt, to the greater expansion and contraction of the zinc—so considerable in such varying temperatures as it is exposed to in a boiler—being so much greater than that of the iron. The crust formed, during working, on the surface of the metals thus gets broken when the boiler is cooling, leaving the surface of the iron round the edges of the zinc plates, or disks, exposed, whilst the boiler is open, to moisture of the worst kind.

In cold water, and in water kept steadily at a high temperature, this species of corrosion (grooving) does not occur; and if care were taken to prevent unequal expansion and contraction of a boiler, and to keep it dry when idle, grooving along the seams would be prevented.

It was on account of the unequal expansion and contraction of the two metals, and with the double view of utilizing the zinc surface to the greatest possible extent, and of ensuring better distribution and contact between the zinc and the boiler, that the Author adopted the stud-and-collar attachment which has been found so very successful in practice in the prevention of corrosion in boilers.

In this series the zinc disks were in direct contact with the plates, except in the case of No. 4, where there was a small washer between the zinc and the plate as shown in Fig. 1. The oxide was taken off the disks, and the disks were made bright every three months.

The results of the second series of experiments are given in Table II in the Appendix. Of the differences in the effects of the various cold liquids on the iron, the most noteworthy is that between specimens Nos. 3, 4, and 5. No. 3 was in sea-water boiled only; No. 4 was in water of $\frac{7}{32}$ density, that is, sea-water boiled down to one-seventh its original volume; whilst No. 5 was in sea-water boiled only for a few minutes, and then immediately corked and sealed up. Had the air been expelled in this case, and afterwards effectually excluded, as was intended, no oxidation of the iron, of course, could have taken place.

Although plate No. 4 lost 19 grains, its surface was perfectly smooth and showed no signs of corrosion, but it was plated nearly all over, with a film of copper, which, however, was easily rubbed off the lower end, here and there, with a cloth. The presence of this film was doubtless due to the brass wire by which the specimens were suspended. Originally only $\frac{1}{25}$ inch in diameter, it was in bottle No. 4, considerably reduced by corrosion from the water-level downwards. The plates, it is true, were well clear of the wire throughout, but those in the bottles containing sea-water were all more or less affected, although, excepting No. 4, there was no copper deposit.

It seems remarkable that the loss of weight in No. 4 was only one-fourth that of No. 3, and that the conditions were such as to promote electroplating.

The different effects of the liquids that had been boiled, and of those not boiled, especially in the case of sea-water, are also rather remarkable. In this series again the protection afforded by the zinc in sea-water to the plates to which it was attached is marked. In fact, with a certain surface of zinc, and if due attention is paid to the periodical removal of the oxide found upon it, polished surfaces of iron and steel can be thoroughly preserved for any

length of time. This was the case with plates Nos. 8 and 10, for although two small spots of rust formed on No. 8, due to the failure to remove the oxide for nearly eight months, the corrosion ceased immediately on the oxide being removed.[1] Plate No. 10 was bright on one side and edge, and on half the other side and edge, the rest, except the ends, retaining the original scale. No zinc was attached to this plate during the first twelve months, in which period it lost $16\frac{1}{4}$ grains; but zinc being then applied corrosion ceased. The zinc disks were attached as shown in Fig. 1. In No. 9 the zinc was similarly attached, except that the small washer between the disk and the plate was dispensed with, and the zinc separated from the plate on the one side, and the nut on the other; and also from the bolt, by a thickness of writing paper only, which was sufficient to insulate the metals. As a consequence the plate lost within 3 grains as much as No. 7. In bottle No. 9 another piece of zinc was also suspended, but quite clear from the iron.

A few words may here be added as to the effects of zinc in sea-water, other than the protection it affords to iron. Within half-an-hour of the immersion of the plates, the surfaces both of the iron and of the zinc being clean, minute globules of gas begin to form on and adjacent to, the zinc. These gradually spread and increase in size until they are disturbed by vibrations, or become too large to remain under water, when they find their way to the surface. The surface of the iron, on the other hand, becomes gradually coated with a thin deposit, white and hard after drying; and there are thrown off from it and from the bottle, on the slightest touch, exceedingly light chalky particles which slowly find their way to the bottom. This goes on until the zinc becomes inactive and ceases to attract or cause any more globules of gas to form; but on removing from it the oxide with which it is then found to be coated, the same effects as before are produced. Crystals of a kind of salt unknown to the Author are also found upon the zinc and the parts adjacent to it.

In this series the liquids were changed entirely, and the oxide was scraped off the specimens only twice during the whole period. The deficiencies due to evaporation, namely, about 15 per cent. in the case of fresh water, 10 per cent. in sea-water, and 5 per cent. in water of $\frac{7}{32}$ density, were made good twice annually. The

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[1] These two plates are still under test, and consequently they have been exposed a year longer than the rest, without showing any change in their condition.

proportion of zinc to iron surface was as 1 to 16, being the same as in the first series.

The amount of zinc expended in protecting plates Nos. 8 and 10 during the whole period, including the loss through filing the parts covered by the nuts on the one side, and the washer on the other, which remained always bright and unaffected, and making the affected surface bright all over—in all about 40 per cent.—was 3 oz. 55 grains. The time occupied was five years and ninety-three days, except in the case of No. 10, when it was twelve months less.

Of Series III still less may be said, as, with the exception of some particulars as to the proportions of surface exposed, Table III. and Figs. 3, 4, and 5, give all information. Although the results obtained may not be considered of much practical value, the Author thinks they are worth placing on record, in view of the time and trouble expended upon the experiment.

Fig. 3 shows how Nos. 1 to 9 were fitted, except that the copper attached to No. 2, and the iron attached to No. 4, were not screwed up to within $\frac{1}{16}$ inch of the plates. With the exception of Nos. 10 and 11 all are comparable, both as regards the proportion of surface exposed and water; excepting No. 9 they were all suspended in the same vessel. No. 9 was placed in a bottle on account of the sulphurous nature of the rubber attached to the plate, which it was thought might affect the other specimens if suspended in the same vessel.

With respect to Table III. and Figs. 3, 4, and 5, the Author was not prepared to see such trifling differences in the losses of weight, especially in the case of Nos. 1 and 3. No. 9 with the rubber attached lost the least, as if it had been somewhat protected; but this might have been due to the quantity of water contained in the bottle, or to the smaller quantity added annually, or to both. Of this notice will be taken farther on. To plate No. 10 a copper plate of equal size was connected by a copper rod, with an iron nut on one side of each plate, and a copper nut on the other, as shown in Fig. 4. Nevertheless, the loss of weight did not amount to quite twice that of No. 4, in which the proportion of exposed surface was only 1 to 6; but the corrosion was much more marked near the nuts, and under and close to them the plate was slightly grooved on each side about one-third round. Of this peculiar corrosion there was no sign in any of the other specimens. No. 11 was a disk cut out of a copper-plated tube, suspended on a glass button, as shown in Fig. 5. It was rough on the in- or under-side, and bright round the edge and hole, and at the part H on one side

of the hole. The proportion of surface protected by the copper to that of the exposed iron in this was as 1 to 1·8. The time occupied was five years and seventy-four days, except in the case of No. 11, in which it was only four years and two hundred and ninety-nine days.

The Author will next draw attention to the differences in the results, though they are not very great, in those cases which are comparable in Series II and III. These are No. 7 in Series II, and No. 3 in Series III. The difference in the average loss per square foot of surface per annum is 92·2 grains, or nearly 27 per cent. in favour of the former, which was probably due to the water in the former case being changed only twice during the whole period, whilst in the latter nearly 25 per cent. had to be added four times a year, in order to keep the plates immersed, in consequence of the porous nature of the containing vessel.

That periodical changes of, or additions to, the water act injuriously on the iron immersed may be regarded as established; but the Author has come to the conclusion, from further experiments, that there are other conditions to which attention should be directed, in order, as far as possible, to make a fair comparison of the results obtained. These are:—1. The volume of water, if quiescent, in which the iron is placed; 2. The extent of surface of iron exposed, and the frequency of cleaning and consequent exposure of fresh surface; and 3. In the sea or other active water, the current and the consequent ceaseless change of water, and of the very agents which act injuriously on iron.

In confirmation of these views the Author would refer to the results obtained by him from an experiment in still sea-water with Yorkshire iron, similar to that used in the experiment under notice.[1] No change of water or addition was made for two years, and the iron lost an average of 130·1 grains only per square foot of surface per annum; whilst in bottle 7, Series II, in which, except as to the quantity of water and the additions to make good the waste, the conditions were similar, the iron lost an average of 250 grains per square foot of surface per annum during five and a quarter years. In the first-named case there was an aggregate exposed surface of iron and steel of 151·5 square inches in 2 gallons of water, whilst in the last-named there was a surface of only 11·8 square inches in a little more than a quart of water.

Without further reference to these series, the Author in conclusion will allude to the results of some experiments made by

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[1] Minutes of Proceedings Inst. C.E. vol. lxv. p. 84.

him, and which are still going on, to test the effects of active sea-water on steel and iron of the same quality as before. During four years' immersion, namely, to the date of the last examination, the average loss per square foot of surface per annum amounted to 976 grains, whilst in the experiment conducted by Mr. Farquharson of the Admiralty in Portsmouth Harbour,[1] the iron lost during six months' immersion an average of 825 grains per square foot of surface per annum. In the latter case, however, the quality of the iron tested is not given; and in this—and in the fact that the iron in the Author's experiment had not only been deprived of its oxide scale but also of its surface, and made bright, whilst in Mr. Farquharson's it was only deprived of its oxide by the acid process—may be sought the explanation of the small difference. Be this as it may, however, if the effects of greater depth of immersion, if any, be disregarded, this important fact is clearly demonstrated, that the destructive action of active water in the open sea is over seven times that of still sea-water; and a fair illustration is thus afforded of how the results of laboratory experiments lasting only for short periods, and in which no change either as to water or cleaning takes places, are apt to be misleading and misunderstood.

The Paper is accompanied by a drawing, from which the Figs. in the text have been prepared.

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[1] Transactions of the Institution of Naval Architects, vol. xxiii. p. 143.

[APPENDIX.

APPENDIX.—TABLE I.

No. of Bottle.	No. of Plate.	Kind of Water Used.	How often Changed.	Waste through Evaporation made up with	With or without Zinc attached.	Density of the Water in Bottles at different Stages.	Loss of Weight. During 12 Months.	Loss of Weight. Average per Sq. ft. of Surface per Annum.	Remarks on the appearance of the Surfaces after experiment.
							Grains.	Grains.	
1	1	Sea	Every 14 days	Sea-water, about $\frac{1}{10}$th of the whole daily	With	$\frac{2\cdot25}{32}$	1·85	20·7	Surface generally unaffected—only discoloured; but slightly grooved round the edge of zinc disk, which is the case in all that had the zinc in direct contact with the iron.
	1A	..	..	..	Without	..	34·1	383·6	Corroded rather badly, in patches, on one side and edge; the rest much less so.
2	2	Sea	Every 3 months	Rain-water, and $\frac{1}{20}$th sea-water weekly	With	$\frac{1\cdot75}{32}$	2·1	24·2	Much the same as 1 in every respect.
	2A	..	..	..	Without	..	32·25	362·8	Corroded in patches; some portions of the surface unaffected.
3	3	Sea	Once, after 6 months	Rain-water and $\frac{1}{10}$th sea-water weekly	With	$\frac{2\cdot25}{32}$	1·75	20·1	Unaffected, except slight grooving round the zinc disk.
	3A	..	..	..	Without, but connected to 3 plate	..	0·25	2·8	Perfect all over. Only discoloured.
4	4	Rain	Once, after 6 months	½ sea-water and ½ rain-water, daily	With, having a small washer between	$\frac{4\cdot75}{32}$	0·5	5·7	Also perfect; and no signs of grooving round the washer between the zinc disk and plate.
	4A	..	..	..	Without	..	17·6	198·0	This is the least affected of those having no zinc attached. Corrosion general, in the form of etching.
5	5	Rain	Once, after 6 months	Rain-water	With	$\frac{0}{32}$	18·6	214·3	Scarcely any difference between this and the last plate.
	5A	..	..	..	Without	..	21·1	237·4	Much the same as the last two.
6	6	Rain[1]	Every 3 months	Rain-water	With	$\frac{0\cdot25}{32}$	2·25	25·9	Unaffected, except slight grooving round the zinc disk.
	6A	..	..	..	Without	..	40·75	458·4	Corrosion uniform, etched, and in appearance less marked than 1A.
Boiler	7	Rain	Every 3 months	Rain-water	With	$\frac{0\cdot25}{32}$	7·2	82·9	Corroded principally at the top end, and slightly grooved round the zinc disk; some portions of the surface being unaffected.
	7A	..	..	..	Without	..	52·1	586·1	This is much the worst of all; corroded in patches, especially at the top end.

[1] This bottle had 125 grains of common salt, 10½ grains of sulphuric acid, and 5½ grains of chloride of magnesium in it.

APPENDIX.—Table II.

Number of Bottle and Plate.	Kind of Water Used.	Boiled or not.	Open, or with the Air excluded.	With or without Zinc attached.	Loss of Weight. During 5 Years and 93 Days.	Loss of Weight. Average per Square of Surface per Annum.	Remarks on the appearance of the Surfaces after experiment.
					Grains.	Grains.	
1	Distilled	Boiled	Open	Without	85·2	182·4	Corrosion even and general, except at the ends, where it is much less severe, and in places scarcely affected at all.
2	Rain	..	..	..	78 4	167·8	Much the same as 1 in appearance, but less affected, and the corrosion a little more general.
3	Sea	..	..	..	77·3	165·5	Corroded evenly all over, and the crystals of the metal showing bright and sparkling.
4	$\frac{7}{33}$ density	..	..	..	19·6	41·9	Very slightly affected; surface smooth and coated with a film of copper over $\frac{3}{4}$ths of it, downwards.
5	Sea	..	Air excluded	..	30·0	64·2	Slightly etched all over.
6	Rain	Not	Open	..	105·0	224·8	Much the same as 1 and 2, but more severely affected, except about $\frac{3}{8}$ inch of the ends and along the edges, which are unaffected.
7	Sea	..	..	..	116·8	250·1	Very little difference between this and 3, except that the corrosion is more marked.
8	..	..	..	With	2·5	5·5	Very slightly corroded; a spot above the zinc disk, and another above top hole, otherwise perfect and bright.
9	..	..	..	With, but insulated	113·5	248·8	Much the same as 7 in every respect. No protection afforded by the zinc.
10	..	..	..	With	2·2 During 4 years and 93 days	5·9	No difference, since the zinc disk was attached. Polished edge perfect and bright.

Note.—After the first twelve months, one edge of No. 10 was polished.

APPENDIX.—Table III.

No. of Plate.	Kind of Metal or Material attached.	Loss of Weight. During 5 years and 74 days.	Loss of Weight. Average per Square Foot of Surface per Annum.	Remarks on the appearance of the Surfaces after Experiment.
		Grains.	Grains.	
1	Copper, in contact.	153·3	370·8	Corrosion even and general; but a little more marked towards the lower end. Surface under the copper unaffected, and no signs of grooving in proximity to it.
2	Copper, loose, 1/16 inch off.	171·5	369·4	Much the same as 1, except the entire surface is affected.
3	Iron, in contact.	141·5	342·3	Slightly less marked than 1, otherwise it is much the same.
4	Iron, loose, 1/16 inch off	158·8	342·0	Scarcely any difference between this and last, except that the entire surface is affected.
5	Brass, in contact.	147·6	357·1	Much the same as 1, except that it is evenly affected all over.
6	Lead, in contact.	148·0	358·0	Much the same as last, but a little more dirty. Cinder.
7	Whitelead, in contact.	145·4	351·7	This looks worse than the last, showing the fibres of the metal, longitudinally.
8	Redlead, in contact.	154·5	373·8	Much the same as 1 in every respect.
9	Vulc. Rubber, in contact.	137·5	332·6	Much the same as 7, but less marked.
10	Copper, to a copper stay	266·6	574·2	Severely corroded, especially the top end round the stay, where it is grooved one-third round the nut on each side; otherwise the corrosion is general.
11	Copper-plated, iron disk.	58·7 during 4 years and 299 days.	512·8	This is much more affected at the thinnest part of the edge in a line with the hole, and the portion deprived of the copper on one side of the hole. The under surface (rough) was for some time, no doubt, protected by its own oxide scale, but which has entirely disappeared. The copper plating is perfect all over.

Note.—The exposed surface of Nos. 1, 3, 5, 6, 7, 8 and 9 was = 11·44 square inches, and of Nos. 2, 4 and 10 = 12·85 square inches. No. 11 had a surface of 3·42 square inches, of which 1·95 square inch plated with copper.

(*Paper No. 2171.*)

"Coefficients of Discharge applicable to certain Submerged Weirs of large dimensions."

By Robert Hunter Rhind, M. Inst. C.E.

The weirs to which reference is made in the present Paper are some of those which have been constructed, at the expense of the Government of India, across the beds of the large water-courses which intersect the province of Orissa, in order to supply the irrigation-canals with water, and they are situated upon the main branches of the Mahanuddy, Brahmini, and Byturnee rivers.

The reduced levels of the water above and below these large weirs have been observed during very high floods, which completely submerged the masonry-work in the river-beds; and the flood-discharges of the main branches upon which they are placed have been calculated from cross-sections, and with the surface falls obtained from flood-marks, by means of the well-known formula used by Humphreys and Abbot for the Mississippi river.

The calculated discharges of the rivers which are affected by the weirs are as follow:—

	Cubic feet per second.
Mahanuddy River: Flood of 1872.	
Katjooree branch	786,703
Mahanuddy "	609,213
Beropa "	112,662
Brahmini River: Flood of 1881.	
Brahmini branch	307,349
Pattia "	113,798
Byturnee River: Flood of 1881.	
Byturnee and Burrah branches	259,926

The quantity of water which actually passed over each of these two weirs, at the top of the flood of 1881 in the Byturnee, could not be ascertained, because the tract of country between the Byturnee and Burrah branches immediately below the site of the weirs, was wholly submerged by the flood-waters, so that the quantity which was due to each branch could not be distinguished.

It will therefore be necessary to treat these two weirs as one work, when determining the coefficient of discharge applicable to them.

The data for calculating the discharges of the various weirs are as shown below:—

I. Mahanuddy River.

(1) For the Katjooree weir—	Feet.
Length of body-wall	3,433
Length of shore-sluices	90
Length of breaches	324
Total length of overfall	3,847

Value of d, or Head.

	Foot.
At the left bank of the river	1·00
At the right bank of the river	0·05
Mean	0·525

Total discharging areas.

	Square feet.
Between upper and lower water-levels	2,020
Below lower water-level	78,096
Total	80,116

This weir is furnished with a set of shore-sluices, which have narrow openings, and are placed at the south end of the work; and in the flood of 1872 several large breaches occurred in the body-wall, in consequence of the action of parallel currents upon the sandy bed of the river, which had a joint length of 324 feet, and a joint area below the lower water-level of 8,128 square feet; so that, when account is taken separately of these deep openings, the discharging areas will be as follow:—

For the Shore-Sluices.

	Square feet.
Between upper and lower water-levels	47·25
Below lower water-level	2,700·00
Total	2,747·25

For the Large Breaches.

Between upper and lower water-levels	170·10
Below lower water-level	8,128·00
Total	8,298·10

For the Body-Wall.

Between upper and lower water-levels	. . . . . .	1,802·33
Below lower water-level	. . . .	67,268·00
	Total . .	69,070·33

Surface velocity of approach, 11·62 feet per second.

(2) For the Mahanuddy weir—

		Feet.
Length of body-wall	. . . .	5,696·25
Length of shore-sluices	. . . .	190·00
Length of centre-sluices	. . . .	460·00
Total length of overfall	. . . .	6,346·25

Reduced levels of Masonry Work.

Crest of body-wall	. . . .	64·50
Floor of shore-sluices	. . . .	58·50
Floor of centre sluices	. . . .	58·75

Flood-levels in the Flood of 1872.

Above the weir	. . . .	75·95
Below ,,	. . . .	73·95
Value of *d*, or head	. . . .	2·00

Surface velocity of approach, 7·74 feet per second.

Total discharging areas.

		Square feet.
Between upper and lower water-levels	. . . .	12,693
Below lower water-levels	. . . .	63,757
	Total . . .	76,450

Discharging areas for Shore-Sluices.

Between upper and lower water-levels	. . . . .	380·00
Below lower water-level	. . . .	2,935·50
	Total . .	3,315·50

Discharging areas for Centre-Sluices.

Between upper and lower water-levels	. . . . .	920·00
Below lower water-level	. . . .	6,992·00
	Total . .	7,912·00

Discharging areas for Body-Wall.

Between upper and lower water-levels	. . . . .	11,392·50
Below lower water-level	. . . .	53,829·56
	Total . .	65,222·06

(3) For the Beropa weir—

	Feet.
Length of body-wall	1,607
Length of piers	118
Length of left shore-sluices	100
Length of right shore-sluices	155
Total length of overfall	1,980

Reduced levels of Masonry Work.

	Feet.
Crest of body-wall	63·50
Crest of piers	67·50
Floor of left shore-sluices	58·50
Floor of right shore-sluices	58·50

Flood-levels in the Flood of 1872.

Above the weir	71·80
Below "	70·60
Value of d, or head	1·20

Surface velocity of approach, 6·65 feet per second.

Total discharging areas.

	Square feet.
Between upper and lower water-levels	2,376
Below lower water-level	14,861
Total	17,237

Discharging areas for the left Shore-Sluices.

Between upper and lower water-levels	120·00
Below lower water-level	1,210·00
Total	1,330·00

Discharging areas for the right Shore-Sluices.

Between upper and lower water-levels	186·00
Below lower water-level	1,875·50
Total	2,061·50

Discharging areas for Body-Wall and Piers.

Between upper and lower water-levels	2,070·00
Below lower water-level	11,775·50
Total	13,845·50

II. Brahmini River.

(1) For the Brahmini weir—

	Feet.
Length of shore-sluices	389
Length of piers	140
Length of body-wall	3,471
Total length of overfall	4,000

Reduced levels of Masonry-Work.

Floors of shore-sluices	50·50
Crest of piers	60·50
Crest of body-wall	58·00

Flood-levels in the Flood of 1881.

	Feet.	
Above the weir—		
Right bank	68·75	
Left bank	68·30	Mean = 68·52
Below the weir—		
Right bank	68·00	
Left bank	68·10	Mean = 68·05
	Difference	0·47

Value of d, or Head.

	Foot.
At the right bank	0·75
At the left bank	0·20
Mean	0·47

Surface velocity of approach, 6·99 feet per second.

Total discharging areas.

	Square feet.
Between upper and lower water-levels	1,880·00
Below lower water-level	42,767·50
Total	44,647·50

Discharging areas for the Shore-Sluices.

	Square feet.
Between upper and lower water-levels	182·83
Below lower water-level	6,826·95
Total	7,009·78

Discharging areas for the Body-Wall and Piers.

Between upper and lower water-levels	1,697·17
Below lower water-level	35,940·55
Total	37,637·72

(2) For the Pattia weir—

	Feet.
Length below first step of piers	665·00
,, second ,,	725·50
,, third ,,	734·00
Total length of overfall	734·00

Reduced levels of Masonry-Work.

Floor of weir	49·50
Top of first step of piers	60·50
,, second ,,	66·50
,, third ,,	72·50

Flood-levels in the Flood of 1881.

	Feet.	
Above the weir—		
Right bank	69·52	
Left bank	67·90	Mean = 68·71
Below the weir—		
Both banks	67·85	Mean = 67·85
	Difference . .	0·86

Value of d, or Head.

	Feet.
At the right bank	1·67
At the left bank	0·05
Mean . . .	0·86

Surface velocity of approach, 7·84 feet per second.

Total discharging areas.

	Square feet.
Between upper and lower water-levels	631·24
Below lower water-level	12,658·90
Total . .	13,290·14

III. BYTURNEE RIVER.

(1) For the Byturnee weir—

	Feet.
Length of shore-sluices	100
" piers	14
" body-wall	912
Total length of overfall	1,026

Reduced levels of Masonry-Work.

Floor of shore-sluices	48·50
Crest of piers	58·92
Crest of body-wall	55·76

Flood-levels in the Flood of 1881.

Above the weir	66·60
Below the weir	63·79
Value of *d*, or head	2·81

Surface velocity of approach, 8·51 feet per second.

Total discharging areas.

	Square feet.
Between upper and lower water-levels	2,883·06
Below lower water-level	8,920·54
Total . .	11,803·60

Discharging areas for the Shore-Sluices.

Between upper and lower water-levels	281·00
Below lower water-level	1,529·00
Total . .	1,810·00

Discharging areas for the Body-Wall and Piers.

	Square feet.
Between upper and lower water-levels	2,602·06
Below lower water-level	7,391·54
Total . .	9,993·60

(2) For the Burrah weir—

	Feet.
Length of shore-sluices	100
„ piers	14
„ body-wall	412
Total length of overfall	526

Reduced levels of Masonry-Work.

Floors of shore-sluices	48·50
Crest of piers	58·92
Crest of body-wall	55·76

Flood-levels in the Flood of 1881.

Above the weir	67·10
Below the weir	63·70
Value of *d*, or head	3·40

Surface velocity of approach, 8·51 feet per second.

Total discharging areas.

	Square feet.
Between upper and lower water-levels	1,788·40
Below lower water-level	4,858 20
Total . .	6,646·60

Discharging areas for Shore-Sluices.

Between upper and lower water-levels	340·00
Below lower water-level	1,520·00
Total . .	1,860·00

Discharging areas for Body-Wall and Piers.

Between upper and lower water-levels	1,448·40
Below lower water-level	3,338·20
Total . .	4,786·60

The formulas which it is proposed to employ for the purpose of calculating the theoretical discharges of the various weirs are as follow :—

(1) For the upper portion, which acts as a weir with a free overfall,

$$V = 5·35 \sqrt{d + 0·035\, a^2} \times C$$

(2) For the lower portion, which acts as a vent or sluice,

$$V = 8·025 \sqrt{d + 0·01\, a^2} \times C,$$

in which—

d = the head, or difference between the reduced levels of the upper and lower waters;

a = the surface velocity of approach;

C = the coefficient of discharge.

The resulting discharges, when C = 1·00, and when the total discharging areas are used, are shown in the Tables below:—

—	Surface Velocity of Approach in Feet per second.		Value of—		Value of—	
	a.	a^2.	0·01 a^2 for the Vent portion.	0·035 a^2 for the Weir portion.	$\sqrt{d+0\cdot01a^2}$ for the Vent portion	$\sqrt{d+0\cdot035a^2}$ for the Weir portion.
I. Mahanuddy River.						
(1) Katjooree Weir .	11·62	135·0244	1·350244	4·725854	1·3694	2·2915
(2) Mahanuddy Weir	7·74	59·9076	0·599076	2·096766	1·6122	2·0240
(3) Beropa Weir .	6·65	44·2225	0·442225	1·5477875	1·2815	1·6576
II. Brahmini River.						
(1) Brahmini Weir .	6·99	48·8601	0·488601	1·7101035	0·9791	1·4765
(2) Pattia Weir . ..	7·84	61·4656	0·614656	2·151296	1·2143	1·7353
III. Byturnee River.						
(1) Byturnee Weir .	8·51	72·4201	0·724201	2·5347035	1·8799	2·3119
(2) Burrah Weir .	8·51	72·4201	0·724201	2·5347035	2·0308	2·4361

—	Discharging areas in square feet.		Mean velocity in feet per second when C = 1·00.		Discharge in cubic feet per second when C = 1·00.		
	Vent portion.	Weir portion.	Vent portion.	Weir portion.	Vent portion.	Weir portion.	Total.
I. Mahanuddy River.							
(1) Katjooree Weir .	78,096	2,020	10·9894	12·2595	858,228	24,764	882,992
(2) Mahanuddy Weir	63,757	12,693	12·9379	10·8284	824,882	137,445	962,327
(3) Beropa Weir .	14,861	2,376	10·2840	8·8682	152,831	21,071	173,902
II. Brahmini River.							
(1) Brahmini Weir .	42,767	1,880	7·8573	7·8993	336,037	14,851	350,888
(2) Pattia Weir . .	12,659	631	9·7447	9·2838	123,357	5,860	129,217
III. Byturnee River.							
(1) Byturnee Weir .	8,921	2,883	15·0862	12·3687	134,577	35,660	170,237
(2) Burrah Weir .	4,858	1,788	16·2972	13·0331	79,175	23,308	102,483

From these Tables it appears that the average coefficients of discharge, namely, those which are suitable to the weirs when it is supposed that the same coefficient is applicable to the deep openings of the under-sluices, and to the comparatively shallow areas above the crests of the body-wall and piers, are as follow:—

Name of Main River.	Name of Weir.	Total calculated discharge when C = 1·00.	Discharge according to Mississippi formula.	Value of the average coefficient of discharge.
Mahanuddy . .	Katjooree . . .	882,992	786,703	0·891
,, . .	Mahanuddy . .	962,327	609,213	0·633
,, . .	Beropa . . .	173,902	112,662	0·648
Brahmini . . .	Brahmini . .	350,888	307,349	0·876
,, . . .	Pattia	129,217	113,798	0·881
Byturnee . . .	Byturnee . . .	170,237	259,926	0·953
,, . . .	Burrah . . .	102,483		

The three weirs upon the branches of the Mahanuddy, and that upon the Brahmini, are of the same general character, and consist of a body-wall of masonry, with drystone aprons above and below, which slope down from its crest at various inclinations to the level of the river-bed.

Each of these weirs is furnished with under-sluices, with their floors practically on a level with the bed of the river; but the number and character of the openings varies in each particular case.

Thus at the Katjooree weir there is only one set of sluices, with narrow openings, at the right bank of the river; while at the Mahanuddy weir there is one set of narrow openings at the right bank, and another of large bays, fitted with folding shutters, at about the centre of its length.

The Beropa weir is also supplied with two sets of scouring-sluices, one set with narrow openings, fitted with sliding shutters, at the left bank of the river, and the other with a single wide opening, closed by folding shutters, at the right bank.

At the Brahmini weir, the under-sluices consist of a set of seven openings, 14 feet and 49 feet in width, placed at the left end of the work; and of another set of sixteen openings, with spans of 14 feet and 46 feet, situated at the right bank.

The Pattia weir has no under-sluices of any kind; it consists of a broad masonry floor, laid at one uniform level for the whole

length of the weir between the abutments, and protected from injury on the upper and lower sides by aprons of drystone work, which slope down from its crest to the level of the river-bed.

The total length of the work is divided into fourteen equal bays, by means of masonry piers, stepped up from the surface of the floor to above the highest flood-level, and carrying a light iron foot-bridge, used when working the folding shutters, which are placed in the lower part of the openings between the piers.

The weirs upon the Byturnee and Burrah branches of the Byturnee river have a vertical body-wall 7·92 feet in height. Over this the flood-water falls on to a masonry floor, the tail of which is protected by a drystone apron; and they are each provided with two under-sluices 50 feet in width, which in the case of the Burrah weir are situated one at each end of the work, and in that of the Byturnee weir are placed side by side at the left flank, with a pier between them.

In order to arrive at values of the coefficients of discharge which are applicable to the bodies alone of the various weirs, it is now proposed to consider the question of the coefficients proper for the under-sluices, and it is thought that this can best be done by the help of the average coefficient obtained above for the Pattia weir—a work which, from the circumstance that no under-sluices are attached to it, resembles the deep and wide openings in the other weirs.

From the data given above for the Pattia weir, it appears that the average discharging areas for each of the fourteen bays are:—

	Square feet.
Between upper and lower water-levels	45·09
Below lower water-level	904·21
Total	949·30

And as the head producing the discharge is 0·86 foot, while the depth of the floor below the lower water-level is 18·35 feet, the average widths for each of the openings will be

	Feet.
For upper, or weir, portion	52·43
„ lower, or vent, „	49·28

from which it will be found that the ratios of width of opening to depth are in this case nearly as follow:—

	Ratio.
For upper, or weir, portion	61 to 1
„ lower, or vent, „	3 „ 1

With regard to the value of the coefficient which is applicable to the weir portion,[1] it appears from the experiments of Poncelet and Lesbros upon notches, quoted by Neville, that the coefficients corresponding to ratios of 2·50 to 1, 5 to 1, 10 to 1, and 20 to 1, are 0·595, 0·611, 0·625, and 0·636 respectively, so that it is probable that the coefficient proper for a ratio of 61 to 1 will be about 0·650.

If this value of $C = 0\cdot650$ be now applied to the calculated discharge of the whole of the weir portion, which has been shown, by the Table for the Pattia weir already given, to amount to 5,860 cubic feet per second when $C = 1\cdot00$, a modified discharge of 3,809 cubic feet is obtained, which, when deducted from the total actual discharge of 113,798 cubic feet per second passing over the weir, leaves a quantity of 109,989 cubic feet as the probable actual discharge of the lower portion of this weir, as compared with the calculated discharge of 123,357 cubic feet given for it by the Table.

From this it appears that the coefficient of discharge applicable to a large orifice of this description, in which the ratio of length to depth is nearly 3 to 1, is about $C = 0\cdot892$, when the head to which the discharge is due is 0·86 foot.

In the case of the Brahmini weir, the under-sluices consist of twenty-one openings, each 14 feet wide, and of two more, one of which is 49 feet, and the other 46 feet in width; while the head, and the depth of the sluice-floor below the level of the lower water, are 0·47 foot and 17·55 feet respectively.

For the upper or weir portion of the discharging-area the ratios of length to depth are nearly as follow:—

	Feet.	Ratio.
Width of sluice,	14	30 to 1
,, ,,	46	98 ,, 1
,, ,,	49	104 ,, 1

And from these it may be concluded as before, that the probable values of the coefficients of discharge will be as shown below:—

	Feet.	
Width of sluice,	14	$C = 0\cdot640$
,, ,,	46	$C = 0\cdot653$
,, ,,	49	$C = 0\cdot654$

For that portion of the discharging area which lies below the

[1] Expériences hydrauliques sur les lois de l'écoulement de l'eau à travers les orifices rectangulaires verticaux à grandes dimensions, enterprises à Metz, 1832.

level of the lower water, it appears that the ratios of length to depth are approximately as follow :—

	Feet.		Ratio.
Width of sluice,	14	. . . .	1 to 1
,, ,,	46	. . . .	3 ,, 1
,, ,,	49	. . . .	3 ,, 1

And it further appears, from the Table of the Metz experiments of Poncelet and Lesbros, given by Neville in his hydraulic formulas, that the coefficients for ratios of 1 to 1 and 3 to 1, for a head of about 6 inches, are respectively 0·597 and 0·623.

The head at the Pattia weir was 0·86 foot, and the coefficient of discharge for the vent portion was found to be C = 0·892 for a ratio of about 3 to 1, whereas the Metz experiments give, for nearly the same head, a coefficient of 0·623, so that it would appear that the coefficients shown by the Metz Table should be increased by 0·269 before they are applied to the large openings now under consideration.

This will make the coefficients of discharge for the vent portion of the under-sluices of the Brahmini weir as shown below :—

	Feet.		
Width of sluice,	14	. . . .	C = 0·866
,, ,,	46	. . . .	C = 0·892
,, ,,	49	. . . .	C = 0·892

And the modified discharges of these large openings will now be as given by the following Table :—

BRAHMINI WEIR UNDER-SLUICES.

Width of Openings in Feet.	Discharging areas in square feet.		Mean velocity in feet per second.		Discharge in cubic feet per second.		
	Vent portion.	Weir portion.	Vent portion.	Weir portion.	Vent portion.	Weir portion.	Total.
14	5,159·70	138·18	6·8044	5·0556	35,109	699	35,808
49	859·95	23·03	7·0087	5·1661	6,027	119	6,146
46	807·30	21·62	7·0087	5·1582	5,658	112	5,770
Total .	6,826·95	182·83	..	..	46,794	930	47,724

The total modified discharge of these sluices, therefore, amounts to 47,724 cubic feet per second; and if this quantity be deducted from the total actual discharge passing over the Brahmini weir,

which was 307,349 cubic feet, the result is 259,625 cubic feet per second as the total probable actual discharge of the body and piers, the total calculated discharge of which, when C = 1·00, is found to be 295,802 cubic feet per second; so that the average coefficient of discharge for this part of the weir will be C = 0·878.

With regard to the coefficients which apply separately to the weir and to the vent portions of the body, the total length of the body-wall and piers is in this instance 3,611 feet, and the depth of the crest of the weir below the level of the lower water is 10·05 feet, while the head is as before, 0·47 foot.

From these figures it appears that the ratios of length to depth are :—

For the weir portion, about	7,683 to 1
For the vent portion „	359 „ 1

And calculating as before, from the notch experiments of Poncelet and Lesbros, the result is a coefficient of about C = 0·661 for the upper or weir portion, so that the modified discharge of this part of the body will amount to 8,862 cubic feet per second, leaving a quantity of 250,763 cubic feet to be passed by the lower or vent portion, the calculated discharge of which (when C = 1·00) is 282,396 cubic feet per second.

The resulting coefficient of discharge for the vent portion will therefore be C = 0·888.

Proceeding in a similar manner with regard to the other weirs, the following results are obtained :—

1st. Byturnee and Burrah weirs.

(1) *For the Byturnee weir.*—The under-sluices have two openings, each 50 feet in length. The head is 2·81 feet, and the depth of the floors below the level of the lower water is 15·29 feet.

Therefore the ratio of the weir portion is about 18 to 1.
„ „ vent portion „ 3 to 1.

Probable coefficients.

For the weir portion, C = 0·634.
For the vent portion, C = 0·621 + 0·269 = 0·890.

Modified discharge of Under-sluices.

		Cubic feet per second.
Weir portion,	281·00 × 7·8418	= 2,204
Vent portion,	1,529·00 × 13·4267	= 20,529
	Total	22,733

(2) *For the Burrah weir.*—The under-sluices have also two openings, each 50 feet in length. The head is 3·40 feet, and the

depth of the floors below the level of the lower water is 15·20 feet.

Therefore the ratio of the weir portion is about 15 to 1.
" " vent portion " 3 to 1.

Probable coefficients.

For the weir portion, $C = 0 \cdot 631$.
For the vent portion, $C = 0 \cdot 620 + 0 \cdot 269 = 0 \cdot 889$.

Modified discharge of Under-sluices.

	Cubic feet per second.
Weir portion, 340·00 × 8·2239	= 2,796
Vent portion, 1,520·00 × 14·4882	= 22,022
Total	24,818

	Cubic feet.
Total actual discharge of both weirs	= 259,926
Less modified discharge of all sluices	= 47,551
Probable actual discharge of bodies and piers of both weirs	= 212,375

Calculated discharge of bodies and piers, when $C = 1 \cdot 00$.

	Cubic feet per second.
For the Byturnee weir	148,694
For the Burrah weir.	73,280
Total	216,974

Therefore average coefficient of discharge for the bodies and piers is $C = 0 \cdot 979$.

Ratios of the Weir portions of the bodies.

For the Byturnee weir, 329 to 1.
For the Burrah weir, 125 to 1.

Probable coefficients for the Weir portions.

For the Byturnee weir, $C = 0 \cdot 660$.
For the Burrah weir, $C = 0 \cdot 655$.

Modified discharges of Weir portions.

	Cubic feet.
For the Byturnee weir, 2,602·06 × 8·1633	= 21,241
For the Burrah weir, 1,448·40 × 8·5367	= 12,365
Total	33,606

Probable actual discharge of bodies and piers of both weirs (see above)	212,375
Less modified discharges of weir portions	33,606
Probable total actual discharge of vent portions . .	178,769

Calculated discharge of vent portions when $C = 1 \cdot 00$.

For the Byturnee weir, $7{,}391 \cdot 54 \times 15 \cdot 0862$	. . . =	111,510
For the Burrah weir, $3{,}338 \cdot 20 \times 16 \cdot 2972$	. . . =	54,403
Total		165,913

Therefore the coefficient of discharge for the vent portions of the bodies and piers of these two weirs will be $C = 1 \cdot 077$.

2nd. Katjooree weir.

(1) The under-sluices have fifteen openings, each 6 feet in length. The head is 0·525 foot, and the depth of the floors below the level of the lower water is 30·15 feet.

Therefore the ratio of the weir portion is about 11 to 1.
" " vent portion " 0·20 to 1.

Probable coefficients.

For the weir portion, $C = 0 \cdot 626$.
For the vent portion, $C = 0 \cdot 545 + 0 \cdot 269 = 0 \cdot 814$.

Modified discharge of Under-sluices.

		Cubic feet per second.
Weir portion, $47 \cdot 25 \times 7 \cdot 6744$	. . . . =	363
Vent portion, $2{,}700 \cdot 00 \times 8 \cdot 9454$	. . . . =	24,153
Total		24,516

(2) The large breaches had two openings, with an average length of 162 feet each. The head was 0·525 foot, and the average depth of the bottom of the breaches below the lower water-level was 25·09 feet.

Therefore the ratio of the weir portion is about 309 to 1.
" " vent portion " 6 to 1.

Probable coefficients.

For the weir portion, $C = 0 \cdot 659$.
For the vent portion, $C = 0 \cdot 633 + 0 \cdot 269 = 0 \cdot 902$.

Modified discharge of large breaches.

		Cubic feet per second.
Weir portion, $170 \cdot 10 \times 8 \cdot 0790$	. . . . =	1,374
Vent portion, $8{,}128 \cdot 00 \times 9 \cdot 9124$	. . . . =	80,568
Total		81,942

	Cubic feet per second.
Total modified discharge of under-sluices and breaches	106,458
Total actual discharge of weir	786,703
Probable actual discharge of body	680,245

Calculated discharge of body when $C = 1 \cdot 00$.

		Cubic feet.
Weir portion, $1,802 \cdot 33 \times 12 \cdot 2595$	=	22,096
Vent portion, $67,268 \cdot 00 \times 10 \cdot 9894$	=	739,235
Total		761,331

Therefore the average coefficient of discharge for the body of this weir is, $C = 0 \cdot 893$.
Ratio of the weir portion of the body = 6,539 to 1.
Probable coefficient, $C = 0 \cdot 661$.

Modified discharge of Weir portion.

$1,802 \cdot 33 \times 8 \cdot 1035 = 14,605$ cubic feet per second.

	Cubic feet.
Probable total actual discharge of body	680,245
Less modified discharge of weir portion	14,605
Probable actual discharge of vent portion	665,640

Calculated discharge when $C = 1 \cdot 00$ . . . . . . = 739,235
Therefore the coefficient of discharge for the vent portion of the body of this weir will be, $C = 0 \cdot 900$.

3rd. Mahanuddy weir.

(1) The right bank under-sluices have thirty-eight openings, each 5 feet in length. The head is 2 feet, and the depth of the floors below the level of the lower water is $15 \cdot 45$ feet.

Therefore the ratio of the weir portion is $2\frac{1}{2}$ to 1.
" " vent portion is $0 \cdot 32$ to 1.

Probable coefficients.

For the weir portion, $C = 0 \cdot 595$.
For the vent portion, $C = 0 \cdot 574 + 0 \cdot 269 = 0 \cdot 843$.

Modified discharge of right bank sluices.

		Cubic feet per second.
Weir portion, $380 \cdot 00 \times 6 \cdot 4429$	=	2,448
Vent portion, $2,935 \cdot 50 \times 10 \cdot 9066$	=	32,016
Total		34,464

(2) The centre sluices had ten openings, each 46 feet in length. The head is 2 feet, and the depth of the floors below the level of the lower water is $15 \cdot 20$ feet.

Therefore the ratio of the weir portion is 23 to 1.
" " vent portion is about 3 to 1.

Probable coefficients.

For the weir portion, $C = 0 \cdot 637$.
For the vent portion, $C = 0 \cdot 622 + 0 \cdot 269 = 0 \cdot 891$.

Modified discharge of centre sluices.

		Cubic feet per second.
Weir portion, 920 × 6·8977	=	6,846
Vent portion, 6,992 × 11·5274	=	80,600
Total		86,946

Total modified discharge of right bank sluices and centre sluices	121,410
Total actual discharge of weir	609,213
Probable actual discharge of body	487,803

Calculated discharge of body when $C = 1 \cdot 00$.

		Cubic feet.
Weir portion, 11,392·50 × 10·8284	=	123,363
Vent portion, 53,829·56 × 12·9379	=	696,441
Total		819,804

Therefore the average coefficient of discharge for the body of this weir is, $C = 0 \cdot 595$.
Ratio of the weir portion of the body = 2,848 to 1.
Probable coefficient, $C = 0 \cdot 661$.

Modified discharge of Weir portion.

$11{,}392 \cdot 50 \times 7 \cdot 1576 = 81{,}543$ cubic feet per second.

		Cubic feet.
Probable total actual discharge of body		487,803
Less modified discharge of weir portion		81,543
Probable actual discharge of vent portion	=	406,260
Calculated discharge when $C = 1 \cdot 00$	=	696,441

Therefore the coefficient of discharge for the vent portion of the body of this weir will be, $C = 0 \cdot 583$.

4th. Beropa weir.

(1) The left bank sluices have twenty openings, each 5 feet in length. The head is 1·20 foot, and the depth of the floors below the level of the lower water is 12·10 feet.

Therefore the ratio of the weir portion is about 4 to 1.
" " vent portion " 0·41 to 1.

Probable coefficients.

For the weir portion, $C = 0 \cdot 604$.
For the vent portion, $C = 0 \cdot 576 + 0 \cdot 269 = 0 \cdot 845$.

Modified discharge of left bank sluices.

		Cubic feet per second.
Weir portion, 120 × 5·3564	=	643
Vent portion, 1,210 × 8·6899	=	10,515
Total		11,158

(2) The right bank sluices have a single opening, 155 feet in length. The head is 1·20 foot, and the depth of the floor below the level of the lower water is again 12·10 feet.

Therefore the ratio of the weir portion is about 129 to 1.
" " vent " " 13 " 1.

Probable coefficients.

For the weir portion, C = 0·655.
" vent " C = 0·644 + 0·269 = 0·913.

Modified discharge of right bank sluices.

		Cubic feet per second.
Weir portion, 186·00 × 5·8087	=	1,080
Vent portion, 1,875·50 × 9·3893	=	17,610
Total		18,690

Total modified discharge of left and right bank sluices	=	29,848
Total actual discharge of weir	=	112,662
Probable actual discharge of body	=	82,814

Calculated discharge of body when C = 1·00.

		Cubic feet.
Weir portion, 2,070·00 × 8·8682	=	18,357
Vent portion, 11,775·50 × 10·2840	=	121,099
Total		139,456

Therefore the average coefficient of discharge for the body of this weir is, C = 0·594.
Ratio of the weir portion of the body, 1,438 to 1.
Probable coefficient, C = 0·661.

Modified discharge of Weir portion.

2,070·00 × 5·8619 = 12,134 cubic feet per second.

		Cubic feet.
Probable total actual discharge of body	=	82,814
Less modified discharge of weir portion	=	12,134
Probable actual discharge of vent portion	=	70,680

Calculated discharge of vent portion, when C = 1·00 = 121,099 cubic feet.
Therefore the coefficient of discharge for the vent portion of the body of this weir will be, C = 0·584.

The coefficients of discharge, for the bodies of the various weirs which have thus been deduced, are collected in the following Table, which also gives the head, depth of water passing over the crest of the body, and the total length of body and piers in each case.

COEFFICIENTS of DISCHARGE for the BODY PORTIONS of the WEIRS.

1	2	3	4	5	6	7	8	9	10
								Coefficient of Discharge.	
Number.	Name of River.	Name of Weir.	Total Length of Body and Piers in Feet.	Depth of Crest of Body below the lower Water-Level in Feet.	Head which produced the Discharge in Feet.	Length of Body, &c., divided by Depth of Crest below Lower Water-Level.	Depth of Crest below Lower Water-Level divided by the Head.	Average Value for both Weir and Vent portions.	Value for the Vent portion alone.
1	Brahmini . . .	Pattia	52·43	18·35	0·860	2·86	21·34	0·881	0·892
2	Byturnee . . .	Byturnee . . .	926	8·03	2·810	115·32	2·86	0·979	1·077
3	Ditto	Burrah	426	7·94	3·400	53·65	2·34		
4	Brahmini . . .	Brahmini . . .	3,611	10·05	0·470	359·30	21·38	0·878	0·888
5	Mahanuddy . .	Katjooree . . .	3,433	19·59	0·525	175·24	37·31	0·893	0·900
6	Ditto	Mahanuddy . . .	5,696	9·45	2·000	602·75	4·73	0·595	0·583
7	Ditto	Beropa . . .	1,725	7·10	1·200	242·96	5·92	0·594	0·584

The Table of the Metz experiments of Poncelet and Lesbros upon the discharge of differently proportioned orifices, which has been previously referred to, shows that, except when the ratio of length to depth is 1 to 1, the coefficient of discharge diminishes as the head increases; and it might be expected therefore, in the case of the four weirs upon the Brahmini, Katjooree, Mahanuddy, and Beropa rivers, which are all of the same general description, that the Brahmini weir would have the highest coefficient of discharge, and the Mahanuddy weir the lowest, whereas it is found in practice that, although the Mahanuddy weir has the smallest coefficient, the Katjooree weir has a higher value of it than the Brahmini.

The Metz Table also shows that when the head producing the discharge is constant, the coefficient of discharge invariably increases as the ratio of length to depth in the sides of the orifice increases, so that on this account it might have been expected that the coefficient would be greatest for the Mahanuddy weir, and least for that on the Katjooree, instead of which an exactly contrary result has been obtained from the foregoing calculations.

It does not therefore appear that the coefficients of discharge, which are given in the last column of the above Table as those for the vent portions of the weirs, can properly be compared either with the heads producing the discharges, or with the ratio of length to depth of orifice; but it would seem that they agree better with the numbers contained in the eighth column, which have been obtained by dividing the depth of the crest below the lower water-level by the head.

(*Paper No. 2184.*)

"English and American Railroads Compared."[1]

By Edward Bates Dorsey, M. Am. Soc. C.E.

(Abstracted by W. B. Worthington, M. Inst. C.E.)

The first thing which strikes an American railway engineer travelling in England is the inconvenience of the passenger carriages. "Stephenson and his colleagues mounted the old stage-coach body on car-wheels, which became the type of the passenger cars; and coal wagons that were then in use in the collieries were put on the railroad, and became the type of freight cars; and before the conservative English character thought that they ought to be improved, and should be changed, the trunk lines had been built and adapted to this narrow and low type of rolling stock to have made it wider and higher later would have required the removing and reconstruction of the masonry platforms, the raising and widening of bridges and tunnels—in fact, almost a reconstruction of the road."

Laying out the Line.—English railways are laid out with easier curves and gradients than American railways, and much money and time is spent in attaining this object. Recently English engineers have introduced in their new lines gradients and curves which in the early days of railways would have been considered impracticable. Few English lines attain a greater altitude than 900 feet above the sea, there being no high backbone ranges to be crossed as in America. Probably, the whole of England will compare, as regards the physical features of the country in relation to railway construction, with the United States, after excluding the strictly prairie States. About half the American railways are constructed in country offering no greater advantage than the United Kingdom for cheap construction.

Cost of Land and Right of Way.—This is much greater in England than in America.

Construction.—"This is generally much superior, stronger, more substantial, and a great deal more costly on English" than on

[1] The original article appeared in the Transactions of the American Society of Civil Engineers for January, 1886, and is the Paper referred to by Mr. R. Gordon, "On the Economical Construction of Railways, &c.," *ante*, p. 54.

American lines. Especially is this so in the case of new lines, the American system of "rushing" the line through and completing it at leisure being unknown in England, where the Board of Trade requirements must be satisfied before the line is opened. The American wooden culverts and trestle-work are almost unknown in England. Embankments are made with flatter slopes, and more attention is paid to foot and side drains than in America.

Passenger Carriages.—English carriages are narrower than American, the Pullman cars used in England being 8 feet 10 inches wide as compared with 10 feet, and being also 13 inches lower. "The English passenger car is cold in cold weather and hot and close in warm weather. If one is seated facing the engine, he is in a gale; if seated on the front seat, is in a corner where no air can reach him. It does not run as smoothly as the American."

All the railways in the United Kingdom, except the Midland, run virtually six classes of carriages, viz., 1st, 2nd, and 3rd smoking and non-smoking; and as it is impossible to fill all these uniformly, there is great loss of room and unnecessary haulage of dead weight.

There is nothing in America corresponding to the workmen's trains, which are run morning and evening by many English companies at very cheap rates.

Goods Wagons and Trains.—The English goods wagon weighs about 5 tons and carries 8 tons, a proportion of 1 to 1·6. The American box freight car weighs 23,000 lbs. and carries 50,000 lbs., a proportion of 1 to 2·13.

English goods trains run at much higher speeds than American, and they do not average one-half the load of American trains; while, considering the better construction of the roads, and the comparatively straight lines and easy gradients, the average train-tonnage should be much larger. By reducing the speed and increasing the load of English goods trains the cost of transportation could probably be largely reduced.

Block System.—The English railways have a great superiority over the American lines in their thorough adoption of the block system.

Baggage Checks.—English railways are behind American in arrangements for dealing with passengers' luggage, the baggage check system being brought to great perfection in America.

Speed.—In England goods trains run much faster than in America. Passenger trains also are generally faster in England than America. The accompanying Table gives the average speeds of some express services:—

[Taken from Table No. 1.]

—	From	To	Distance in Miles.	Average Miles per Hour including Stoppages.
English—				
London & North Western	London .	Liverpool .	201¾	44·8
" "	" .	Glasgow . .	406	40·6
" "	" .	Holyhead .	264	43·4
Great Northern . . .	" .	Glasgow . .	444	43·0
" " . . .	" .	York . . .	188¼	48·1
Great Western . . .	" .	Bristol . .	118½	45·6
London, Brighton, and South Coast . . .	" .	Brighton. .	50	46·2
Midland	" .	Nottingham.	125	50·0
American—				
New York, New Haven, and Hartford . . .	Boston . .	New York .	234	39·0
Pennsylvania	Jersey City	Philadelphia	89	45·6
"	" .	Chicago . .	911	36·8
New York Central and Hudson River . . .	New York .	Albany . .	143	44·0
" "	" .	Buffalo . .	441	41·0
" "	" .	Chicago . .	980	39·2
Baltimore and Ohio . .	Baltimore .	Washington.	40	53·0

Accidents.—Table showing passengers killed and injured from causes beyond their own control on all the railways of the United Kingdom, and those of the States of New York and Massachusetts, 1884.

[Taken from Table No. 2.]

—	Total Length of Line Worked.	Total Mileage.		Killed.	Injured.
		Train.	Passenger.		
United Kingdom	18,864	272,803,220	6,042,659,990	31	864
New York . .	7,298	85,918,677	1,729,653,620	10	124
Massachusetts .	2,852	82,304,338	1,007,136,376	2	42
In 1,000,000,000 passengers transported 1 mile . . .	United Kingdom . . .			5·15	143
	New York			5·78	70
	Massachusetts			2·00	42

—	Average number of Miles a Passenger can Travel without being	
	Killed.	Injured.
United Kingdom .	194,892,255	6,992,662
New York . . .	172,965,362	13,940,754
Massachusetts . .	503,568,188	23,955,630

This comparison is with two of the States in which there are old and completed railways. The Western States would show a much higher proportion of accidents.

[TABLE No. 4.]

NUMBER of PERSONS EMPLOYED on the RAILWAYS of the UNITED KINGDOM and the UNITED STATES in 1880.

1880.	United Kingdom.	United States.
Engine-drivers and firemen	27,441	67,231
Guards	12,064	12,419
Platelayers	26,156	
Pointsmen, &c.	7,406	122,489
Labourers	42,212	
Other railway servants	120,437	216,818
Total	235,716	418,957
Average employees per 1,000 miles of goods and passenger trains	0·89	1·08
" " " mile of line open	13·0	4·8
" " " 1,000 tons of traffic	0·9	0·7
" " " 1,000 passengers carried	0·38	0·65
" " " £1,000 earned	2·7	0·28

This Table is taken from a report by Mr. J. S. Jeans, Secretary of the Iron and Steel Institute.

TABLE No. 5.

(Compiled by Mr. J. S. JEANS.)

SHOWING the ROLLING STOCK used on RAILROADS of UNITED KINGDOM and UNITED STATES in 1880.

1880.	United Kingdom.	United States.
Locomotives	14,469	17,412
Passenger carriages	32,804	12,380
Freight cars	446,833	375,312
Other vehicles	12,024	84,613
Totals	505,130	489,667
Vehicles per mile open	2·6	0·24
" " 1,000 tons freight carried	0·5	0·59
" " 1,000 passengers "	1·3	0·53
" " £1,000 capital	1·5	2·3

RAILWAYS of the UNITED KINGDOM and the UNITED STATES COMPARED, 1883.

[Taken from Table No. 16.]

—	United Kingdom. Total.	United Kingdom. Per Mile Worked.	United States. Total.	United States. Per Mile Worked.
Single line . . . miles	8,576	..	..	..
Double or more lines ,,	10,105	..	..	..
Total miles . . .	18,681	..	110,414 (about 23 per cent. double.)	..
Capital.				
Shares and stock	£588,998,127	£31,529	£741,612,117	£6,152
Loan and debenture stock .	166,563,552	8,916	..	..
Bonds	..	..	691,008,077	5,730
Floating debts	..	..	55,474,069	..
Total	£755,561,679	£40,445	£1,488,094,263	£11,882
Train Service.				
Total mileage of passenger trains . . .	138,176,940	..	193,960,013	..
,, ,, of freight trains	127,983,253	..	350,108,255	..
,, ,, ,, mixed ,,	2,737,043	..		..
,, train mileage . .	268,897,236	..	544,068,268	..
Freight Traffic.				
Total tons of freight moved . . . . tons	266,382,968	..	400,453,439	3,627
Total ton-mileage .	9,288,316,560	..	44,064,923,445	..
Average train-load . ,,	71	..	126	..
Total freight receipts .	£38,701,319	£2,072	£109,951,339	£1,000
Average receipts per ton moved . . pence	33·6	..	65·9	..
Average charge per ton per mile . . ,,	..	1	..	0·595
Average mileage of each ton moved	35	..	110	..
Passenger Traffic.				
Total number of passengers of all classes	684,350,187	36,632	404,811,584	3,666
Total passenger mileage .	5,969,825,966	..	8,817,684,503	..
Average mileage per passenger	7·2	..	22	..

RAILWAYS of the UNITED KINGDOM and the UNITED STATES COMPARED, 1883—*continued.*

—		United Kingdom.		United States.	
		Total.	Per Mile Worked.	Total.	Per Mile Worked.
Passenger Traffic—contd.					
Total receipts from passengers	£	25,742,452	1,378	44,326,616	401
Average receipts from each passenger .	pence	8·9	..	26·28	..
Average mileage of each passenger		8·0	..	22·0	..
Average charge per mile per passenger	pence	..	1·12	..	1·16
Earnings.					
Earnings from freight traffic	£	38,701,319	2,072	109,951,339	1,000
" from passenger traffic . . .	"	25,742,452	1,378	44,326,616	401
" from freight and passenger traffic	"	64,443,771	3,450	154,277,955	1,401
Total earnings from all sources . . .	"	71,062,270	3,804	164,754,585	1,492
Percentage of gross earnings to investment, capital, and bonds		9·05	..	10·99	..
Percentage of net earnings to investment, capital, and bonds		4·29	..	4·49	..
Working expenses . .	£	37,368,562	2,001	97,372,208	882
Percentage of working expenses to receipts . .		53·0	..	59·0	..
Total net earnings . .	£	33,693,708	1,804	67,382,377	610
Percentage of net earnings to gross receipts . .		47·0	..	41·0	..
Passenger earnings per passenger train-mile	pence	..	44·4	..	54·7
Freight earnings per freight train-mile	"	..	72·0	..	74·9
Rolling Stock.					
Total number of engines .		14,469	0·775	23,,823	0·216
" " " passenger cars		32,304	1·73	17,899	0·162
" " " baggage, mail, and express cars .		2,024	0·108	5,918	0·054
" " " freight cars		446,333	23·9	748,661	6·78

Cost of Railways.—The English railways were much more costly than the American. Their expensive construction with straight lines, easy gradients, good road-bed, permanent brick buildings, and brick, stone or iron bridges should make the annual expenses much lighter than those of American lines, where for economical reasons perishable materials, requiring frequent renewals enter so largely into the construction of buildings and bridges.

In order to answer the question: Do the working results compensate for the great additional cost of the English over the American railways? the Author gives a large number of tables based upon information furnished in the half-yearly Reports of the Companies and the Board of Trade Returns in the case of English lines, and upon the Reports of the Railroad Commissioners of the various States in the case of the American lines.

COMPARATIVE PROPORTION of DIFFERENT ITEMS of WORKING EXPENSES which are or are not EFFECTED by GOOD or BAD CONSTRUCTION on the AGGREGATE RAILWAYS of the UNITED KINGDOM and UNITED STATES for the YEAR 1880.

[TABLE No 3.]

(Compiled by Mr. J. S. Jeans.)

1880.	United Kingdom.		United States.	
	Expenses affected by Good or Bad Construction.	Expenses not affected by Good or Bad Construction.	Expenses affected by Good or Bad Construction.	Expenses not affected by Good or Bad Construction.
Maintenance of way . .	17·70	..	25·31	..
Locomotive charges . .	24·40	..	24·96	..
Repairs of carriages . .	8·40	..	9·39	..
Traffic charges . . .	..	30·00	..	25·31
Rates and taxes . . .	..	5·00	..	4·77
Government duty . . .	..	2·40	..	..
Compensation—passengers	..	0·70	..	0·39
" goods .	..	0·60	..	0·59
Legal and parliamentary expenses	..	0·90	..	0·70
Miscellaneous expenses .	..	9·90	..	8·58
Total . . .	50·50	49·50	59·66	40·34

The following Table shows for the chief English railways the percentage of the annual expenditure which is affected by the good or bad construction of the line. This percentage being subtracted from 59·7, the average percentage for American rail-

ways, and the difference multiplied into the total annual working expenses, gives the gross annual saving due to the superior construction of English lines. The fifth column of the Table gives the annual saving per mile, and this, capitalized at 6 per cent., as given in the last column, shows the amount which the engineer would have been justified in expending per mile over and above the cost of the inferior American system.

[Taken from TABLE No. 17.]

Name of Railway.	Length of Line Worked.	Percentage of Working Expenses. Affected by Good or Bad Construction.	Percentage of Working Expenses. Not Affected by Good or Bad Construction.	Annual Saving per Mile by Good Construction as compared with average American.	Annual Saving capitalized at 6 per cent.
	Miles.			£.	£.
Average of all railways of United Kingdom	18,681	51·8	48·2	158	2,633
London and South Western	721	49·7	50·3	228	3,807
Great Eastern	1,049	53·0	47·0	116	1,932
Great Northern	768	50·7	49·3	223	3,923
Midland	1,381	55·1	44·9	129	2,155
London and North Western	1,793	48·0	52·0	351	5,853
Great Western	2,268	57 2	42·8	42	697
London Chatham and Dover	160	51·5	48·5	299	4,987
Caledonian	897	54·5	45·5	93	1,553
North British	1,006	56·4	43·6	43	720
Average of all railways of United States	110,414	59·7	40·3	..	..

	£.
The average cost of construction of English railways per mile has been (1883)	40,445
The average cost of construction of American railways per mile has been (1883)	12,435
Difference	28,010

The percentage of the working expenses saved by the better construction represented by this amount is 7·9—say 8 per cent. The average annual cost per mile of American railways is £882 per mile; 8 per cent. on this is £71, which would have been the annual saving per mile gained by an increased cost of £28,010 per mile, a return of 0·25 per cent. on the outlay.

Ton- and Passenger-mileage.—No return of ton-mileage is made by the English companies. After careful inquiry the Author decided that the average charge on goods moved in the United Kingdom

is $1\frac{1}{4}d.$ per ton (of 2,240 lbs.) per mile, or, for comparison with American statistics, say $1d.$ per ton (of 2,000 lbs.) per mile. To get the ton-mileage, the receipts from goods traffic, as given by the companies, are multiplied by 240.

The passenger-mileage is obtained by dividing the total receipts from ordinary passengers by the total number carried. This gives the average amount received per passenger. This divided by $1\frac{1}{8}$ (the average rate per passenger-mile on all English railways, 1st, 2nd, and 3rd class included, inclusive of season tickets) gives the average mileage travelled by each passenger. Multiplying that by the number transported gives the total mileage of ordinary passengers. The average mileage travelled for each £1 paid is 206. The average mileage travelled by season-ticket holders for each £1 paid is 600.

The figures for ton- and passenger-mileage of English railways are got by means of these figures from the published half-yearly accounts of the companies. Those for the American railways are taken from the official reports of the companies, or from the reports of the Railroad Commissioners of the different States.

The following Table gives the passenger-mileage and ton-mileage per mile of single line of some of the principal English and American railways :—

TABLE No. 22.

Name of Railway.	Mileage per Mile of Single Line.	
	Passenger.	Ton.
North Eastern	137,000	455,138
Midland	181,272	512,714
London and North Western	283,777	478,912
London, Chatham, and Dover	634,036	195,906
London, Brighton, and South Coast . .	547,328	192,778
Great Western	190,111	308,703
Average	320,587	356,525
Boston and Albany	272,642	609,686
Boston and Providence	492,863	194,772
New York, New Haven, and Hartford .	516,694	314,359
New York, Central, and Hudson River .	182,680	927,978
New York, Lake Erie, and Western . .	114,982	1,216,913
Pennsylvania, Pennsylvania Railroad Division	180,235	1,594,898
Average	285,016	809,767

This Table shows that the six American lines have more than double the goods traffic per mile, and only 11 per cent. less passenger traffic than the six English lines. From this it appears that it is not necessary to run goods trains faster on English than on American lines in order to clear the lines of traffic.

The fast running of the goods trains is one of the main causes of the greater expense of working English as compared with American railways.

Comparing the average of fourteen principal English lines (1883) with ten American lines (1884), the percentages of the total working expenses due to locomotives (running and repairs and renewals) and maintenance of way, &c., are as follow:—

—	Fourteen principal English Railways (1883).	Ten principal American Railways (1884).
Wages of drivers and firemen, and repairs and renewals of locomotives, and cost of fuel . . .	22·1	12·7
Maintenance of way	17·9	21·8

In making the comparison of wages of drivers and firemen the American wages are reduced 50 per cent. to bring them to about the English rate, and all the fuel is reduced to the rate of 6*s.* 5*d.* per ton. The amounts as actually paid are 23·6 and 22·8 per cent. instead of 22·1 and 12·7 per cent. respectively.

The English roads in Table No. 26 (see page 337) were selected by the Author as being five of the roads doing the heaviest and largest traffic in the United Kingdom. The American five were chosen from the eastern system of roads, and are, with the exception of the New York, New Haven, and Hartford, constructed through a country more broken physically than that through which the English roads pass.

Supposing that the longer ton- and passenger-haulage of these five American lines influence the result in their favour, the same calculation on the same basis (except that taxes are included in the working expenses) has been made for 1884 on four of the short lines of Massachusetts, where the average haulage is very short (Table No. 27, page 338).

TABLE No. 26.—COMPARISON of the AVERAGE ANNUAL COST of MOTIVE POWER on FIVE of the PRINCIPAL RAILROADS of ENGLAND and the UNITED STATES for the YEARS 1882, 1883, and 1884.

Name of Railroad.	Total Operating Expenses less Steam-boat Expenses, Taxes, and Duties.	Fuel.			Wages of Engine-drivers and Firemen.			Repairs and Renewals of Locomotives.			Total Percentage of Fuel, Wages of Engine-drivers and Firemen, and Repairs and Renewals of Locomotives to Operating Expenses.	
		Amount actually paid.	Percentage on Operating Expenses.		Amount paid.	Percentage on Operating Expenses.		Amount actually paid.	Percentage on Operating Expenses.		Amount actually paid.	All reduced to English Prices.
			Amount actually paid.	All reduced to English prices. 6s. 5d. per ton of 2,240 lbs.		Amount actually paid.	All reduced 50 per cent. to English prices.		Amount actually paid.	One half of cost of repairs being labour is here reduced 50 per cent. to compare with English.		
England.	£.	£.			£.			£.				
Great Northern . . .	1,998,954	132,495	6·6	6·6	177,270	8·9	8·9	135,734	6·8	6·8	22·3	22·3
North Eastern . . .	3,253,949	219,879	6·8	6·8	317,567	9·8	9·8	405,114	12·5	12·5	29·1	29·1
Midland	3,607,350	227,303	6·3	6·3	425,629	11·8	11·8	351,702	9·8	9·8	27·9	27·9
London and North-Western	4,845,722	271,191	5·6	5·6	453,566	9·4	9·4	364,411	7·5	7·5	22·5	22·5
Great Western . . .	3,512,520	195,945	5·6	5·6	315,892	9·0	9·0	372,298	10·6	10·6	25·2	25·2
Average . .			6·2	6·2		9·8	9·8		9·4	9·4	25·0	25·0
United States.												
Boston and Albany . .	1,076,669	140,488	13·1	4·2	81,388	7·4	3·7	83,546	7·8	5·9	28·3	13·8
New York, New Haven, and Hartford . . .	841,033	85,995	10·2	4·2	50,460	6·0	3·0	30,494	3·6	2·7	19·8	9·9
New York, Lake Erie, and Western . . .	2,649,648	274,134	10·3	6·9	222,894	8·4	4·2	126,495	4·8	3·6	23·5	14·5
New York, Central, and Hudson River . . .	3,669,153	444,844	12·1	6·0	271,231	7·4	3·7	205,712	5·6	4·2	25·1	14·3
Pennsylvania Railroad (Penn. Div.) . . .	3,476,704	221,975	6·4	6·4	247,550	7·1	3·5	295,935	8·5	6·4	22·0	16·3
Average . .			10·4	5·5		7·3	3·6		6·1	4·2	23·7	13·8

[NOTE.—With reference to this Table it is to be noted that the reduced percentages are no longer correct percentages of the total working expenses, and that the total working expenses are not reduced to English rates.—W. B. W.]

TABLE No. 27.

Name of Railroad.	Percentage of Locomotive operating expenses all reduced to the prices paid in England.			
	Coal.	Wages.	Repairs and Renewals of Locomotives.	Total.
Boston and Lowell . . .	4·2	3·7	4·7	12·6
Boston and Maine . . .	4·0	3·3	4·2	11·5
Boston and Providence .	3·1	3·5	5·0	11·6
Old Colony	3·3	3·7	3·6	10·6
Average	3·6	3·6	4·4	11·6

These results show still more favourably to the American system.

Cost per Train-mile.—Owing to the imperfect returns of the cost of motive power made by the English companies, no distinction being made between the goods-mileage and passenger-mileage, comparisons of cost per train-mile are not of much value. A number of Tables are, however, given by the Author which show that although the American average train-load both in goods and passenger trains is much greater than the English, yet the average train-mile costs in motive power less on American than on English railways.

Locomotive Earnings.—More work in a year is got from the locomotives on American railways than on those of Great Britain, as shown by the following Table, which is taken from the reports for 1884:—

[Taken from Table No. 39.]

Name of Railway.	Total Number of Locomotives.	Annual Mileage.	
		Total.	Average.
Great Northern	789	16,978,030	21,498
Great Western	1,577	30,457,257	19,314
Midland	1,697	33,261,729	19,600
London and North Western	2,476	38,184,328	15,422
Totals and average of 13 British railways including the above .	11,320	209,735,248	18,528
Pennsylvania (Pennsylvania division) .	815	20,791,778	25,511
Baltimore and Ohio	603	11,405,777	18,915
New York, Lake Erie, and Western .	805	17,092,582	21,233
Boston and Albany	243	4,960,185	20,407
Totals and average of 16 American railways including the above .	4,479	98,918,986	22,085

The following Table gives the annual traffic earnings per locomotive for 1883:—

[Taken from Table No. 40.]

Name of Railway.	Total Number of Locomotives.	Earnings from Traffic.	
		Total.	Average per Locomotive.
		£.	£.
Great Northern	783	3,522,035	4,805
Great Western	1,577	7,817,742	4,957
Midland	1,629	7,363,217	4,520
London and North Western	2,451	10,362,520	4,228
Totals and average for 14 British railways including the above .	11,554	54,402,781	4,709
Pennsylvania (Pennsylvania division) .	795	6,403,563	8,055
New York and New England. . . .	151	675,260	4,472
New York, Lake Erie, and Western . .	785	4,408,119	5,615
Boston and Albany	244	1,620,391	6,643
Totals and average of 14 American railways including the above .	3,738	27,426,683	7,337

This Table shows that though the average charges for both goods and passengers are lower in America than in England, the average earnings of the American locomotives are much greater than those of the English.

The Author, in conclusion, suggests that English passenger rolling-stock might be improved by the general use of the bogie-truck, which would do away with the jarring caused by the rigid wheel base; and also by warming the carriages in winter; that the comfort of passengers might be much increased, and a saving of porterage staff be effected by the introduction of the American baggage-check system; and that the cost of motive power might be economized by running heavier goods trains at a lower rate of speed. The English road-bed, permanent-way, and block-signalling system he considers to be all that could be desired.

The Paper is accompanied by forty-one statistical Tables and some gradient sections of American railways.

(*Paper No. 2181.*)

"The Maintenance of the Belah and Deepdale Viaducts on the North Eastern Railway."

By WILLIAM JOHN CUDWORTH, Assoc. M. Inst. C.E.

IN a Paper on the Hownes Gill Viaduct in the County of Durham,[1] by the Author's father, William Cudworth, M. Inst. C.E., read on the 25th November, 1862, a comparison was made between that viaduct, which is of firebrick, and the iron viaducts with trellis piers and lattice girders, then recently erected from the designs of the late Sir Thomas Bouch, M. Inst. C.E., to carry the South Durham and Lancashire Union Railway over the Belah and Deepdale valleys.

The Hownes Gill and Deepdale viaducts are of somewhat similar dimensions, but for a single line and double line respectively; and, in order to make the comparison as close as possible, estimates based on the actual cost of both viaducts, were made for a double-line firebrick viaduct over Hownes Gill, and also for a double-line iron viaduct over the same valley, of similar design to that at Deepdale. The estimate in the former case was £20,681, and in the latter, £16,248.

It was thought that the interest on the difference in cost, taken at 5 per cent., viz., £222 per annum, might be absorbed by the needful painting and repairing of the iron viaduct, so that the brick viaduct would not in the long run be more costly. The experience gained by over twenty-five years' use of the viaducts makes it possible to compare this forecast with the actual cost of maintenance. This cost has been as under, over the last eighteen years.

BELAH VIADUCT.

(Length over all, 1,007 feet. Height of rail from bed of stream, 195 feet. For double line.)

	£.	s.	d.
One renewal of timber cross-bearers, way-beams, and planking	1,802	17	2
One additional renewal of way-beams	333	10	0
Painting once every three years, and general repairs	1,395	12	4
Total	3,531	19	6

Divide by eighteen years = per annum £196 4 5.

[1] Minutes of Proceedings Inst. C.E. vol. xxii. p. 44.

Deepdale Viaduct.

(Length over all, 710 feet. Height of rail from bed of stream, 158 feet. For double line.)

	£.	s.	d.
One renewal of timber cross-bearers, way-beams, and planking	1,234	12	8
One additional renewal of way-beams	265	7	9
Painting once every three years, and general repairs	896	5	6
Total	2,396	5	11

Divide by eighteen years = per annum £133 2 6.

From these figures it will be seen that the actual cost of maintenance is less than was expected. Taking the viaducts as unpierced solids, the cost of maintenance is, in the case of Belah, 3*s.* 2½*d.* per 100 cubic yards, and in that of Deepdale 2*s.* 11*d.* per 100 cubic yards, per annum.

The maintenance of the Hownes Gill viaduct has cost a very small sum. With the exception of triennial painting of the cast-iron parapet railing, costing £12 each painting, and of some staging of the cast-iron parapet railing, recently done, at a cost of £47 3*s.* 6*d.*, there has been no expenditure whatever upon it since its completion in 1858. The spandrels will, however, require a little pointing ere long, the cost of which may be estimated at £120. Dividing this and the cost of the staging over thirty years, and adding to it the cost of painting the iron parapet railing, brings the cost of maintenance to only £9 11*s.* 5*d.* per annum.

As the viaducts become older the cost of maintenance of the iron ones might be expected to increase in a more rapid ratio than that of the brick one; but their life has not as yet been sufficiently long to make this apparent.

The Belah and Deepdale viaducts were painted during the summer of 1885; and the cost of painting them was carefully taken out, and is shown below. One coat of paint only was given throughout, and the weather was fine.

Belah Viaduct.

Labour—

	£.	s.	d.		Sq. yards.		Per sq. yard.
Nineteen men at an average rate of 4*s.* 2¾*d.* per day, and one foreman at 6*s.* per day	105	2	6	÷	18,346	=	1·32*d.*

Materials—

	Cwt.		s.	d.		£.	s.	d.		
White lead.	25	at	16	6	=	20	12	6		
Dryers . .	5	„	14	0	=	3	10	0		
Umber . .	3⅛	„	28	0	=	4	7	6		
Red oxide .	3	„	11	6	=	1	14	6		
	Gallons.									
Raw oil .	114	„	1	8	=	12	0	0		
Boiled „ .	12	„	1	9	=	1	1	0		
Turpentine.	12	„	2	0	=	1	4	0		
Brushes, &c.						2	8	6		
									46 18 0 ÷ 18,346	= 0·61

Tackling, &c.—

	£. s. d.		
One-tenth prime cost of ropes, cradles, pulleys, planks, &c., used . . .	8 0 0	÷ 18,346	= 0·21
Superintendence and general charges, 5 per cent.	8 0 0		
Total	£168 0 6		= 2·14*d.*

DEEPDALE VIADUCT.

Labour—

	s. s. d.	Sq. yards.	Per sq. yard.
Nineteen men at an average rate of 4*s.* 2¾*d.* per day, and one foreman at 6*s.* per day	86 0 5	÷ 12,459	= 1·66*d.*

Materials—

	Cwt.	qrs.	lbs.		s.	d.		£.	s.	d.		
White lead	14	3	14	at	16	6	=	12	4	5		
Dryers .	3	2	0	„	14	0	=	2	9	0		
Umber .	1	3	14	„	28	0	=	2	12	6		
Red oxide.	1	1	0	„	11	6	=	0	14	5		
	Gallons.											
Raw oil .	92			„	1	8	=	7	13	4		
Boiled „ .	6			„	1	9	=	0	10	6		
Turpentine	6			„	2	0	=	0	12	0		
Brushes, &c.								1	13	11		
											28 10 1 ÷ 12,459	= 0·55

Tackling—

	£. s. d.		
One-tenth prime cost of ropes, cradles, pulleys, planks, &c.	8 0 0	÷ 12,459	= 0·27
Superintendence and general charges, 5 per cent.	6 2 6		
Total	£128 13 0		= 2·48*d.*

The same ropes, cradles, and other tackling are used for both viaducts, and they are reserved for them alone. Their cost is estimated at £80, and they will last for five of the triennial paintings, great care being taken of them when not in use.

The cost of painting these viaducts compares favourably with that of painting other iron bridges in the same district.

(*Paper No. 2176.*)

"Description of a Circular Chimney-Shaft at Mechernich, near Cologne."

By John Mackworth Wood, Assoc. M. Inst. C.E.

This remarkable chimney-shaft has been erected with a view to get rid of the fumes from the smelting furnaces at the works of the Mechernich Lead-Mining Company, near Cologne, Rhenish Prussia.

The works of the company are situated in the mountains at an elevation of about 2,000 feet above sea-level, and consequently this shaft is exposed to high wind-pressures.

It has been previously stated [1] that it is the tallest shaft in the world, but such is not the case, as there are two taller shafts in this country, namely, the Townsend shaft, Port Dundas, Glasgow; and the St. Rollox shaft, Glasgow; the next in magnitude being the Mechernich shaft. For the sake of comparison the leading dimensions of the three shafts are given:—

Townsend Shaft.

	Feet.	Inches.
Total height from the bottom of the foundation to the top of the coping	468	0
Height from the ground-line to the top of the coping . .	454	0
Outside diameter at the ground-line	32	0
„ „ „ top	13	4

Total weight of the shaft, about 8,000 tons.

St. Rollox Shaft.

	Feet.	Inches.
Total height from the bottom of the foundation to the top of the coping	455	6
Height from the ground-line to the top of the coping . .	435	6
Outside diameter at the foundation	50	0
„ „ „ ground-line	40	0
„ „ „ top	13	6

Mechernich Shaft.

	Metres.	Feet.
Total height from the bottom of the foundation to the top of the coping	134·6 =	441·48
Height from the ground-line to the top of the coping	131·1 =	430·0

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[1] Minutes of Proceedings Inst. C.E. vol. lxxxiii. p. 454.

	Metres.	Feet.
Foundation 12 metres square	12·0=	39·36
Base at ground-line 10 metres square	10·0=	32·8
Diameter at plinth, which is the point where the circular shaft commences, 10 metres (32·8 feet) from the ground-line is	7·5=	24·6
Diameter at the top outside	3·5=	11·48

Total weight of the shaft, 5,459 tons.

The foundations of this shaft are built on the solid rock, called hard "Graywacke," or sandstone, the foundation being constructed of dressed stone (sandstone) masonry, with sloping sides, the dimensions being 12 metres (39·36 feet) square at the bottom, and 10·4 metres (34·11 feet) square at the top, the thickness being 3·5 metres (11·48 feet). The top of this stone foundation is level with the ground-line. From this level the base of the shaft is built 10 metres (32·8 feet) square for a height of 10 metres (32·8 feet); the first 5 metres in height (16·4 feet) of the base being built with vertical sides. Again, from this level the base becomes octagonal, which finishes with a circular plinth 10 metres (32·8 feet) from the ground-line; from the plinth upwards the shaft is circular. In the base of the shaft is an opening for the smoke, 5 metres (16·4 feet) in height. On each side of the base, on the side adjacent to that in which the opening is in, are built buttresses to strengthen the opening. The base, up to the circular plinth, is built entirely of bricks, 250 by 120 by 65 millimetres (9·82 by 4·71 by 2·55 inches), made from fire-clay, which has been burnt in an annular kiln. The circular portion, or stalk of the shaft rising from the plinth to the top, is constructed of radial bricks of yellow clay, 250 millimetres at the longest side, and 100 millimetres thick (9·82 by 3·93 inches), which have been burnt in a gas-chamber furnace.

The top of the shaft or cap is of light, ornamental design, with slight overhanging projections, the ornamental portion being built of the same bricks as the circular shaft itself. No bond iron has been used in the shaft. The batter of the circular shaft or stalk is straight. The flue is 3·5 metres (11·48 feet) in diameter at the bottom of the shaft, and 3 metres (9·84 feet) at the top.

The shaft from the ground-line to the top is divided into twenty-seven sections, the thickness of the walls varying from 3½ metres (11·48 feet) in the base, to 2 metres (6·56 feet) at the commencement of the circular shaft, and again to 0·25 metre (0·82 foot) at the top of the shaft.

—	Metres in Height.	Feet in Height.	Thickness of Wall in Metres.	Thickness of Wall in Feet.
1st section base	10·00	32·80	3·75	12·30
2nd "	3·00	9·84	2·00	6·56
3rd "	3·85	12·62	1·93	6·33
4th "	4·15	13·61	1·86	6·10
5th "	4·00	13·12	1·79	5·87
6th "	4·00	13·12	1·75	5·74
7th "	4·50	14·76	1·68	5·49
8th "	4·25	13·94	1·61	5·28
9th "	4·05	13·28	1·54	5·05
10th "	4·50	14·76	1·47	4·82
11th "	4·15	13·61	1·40	4·59
12th "	4·05	13·28	1·33	4·26
13th "	4·35	14·26	1·26	4·13
14th "	4·30	14·10	1·19	3·90
15th "	4·10	13·44	1·12	3·67
16th "	4·32	14·16	1·05	3·44
17th "	4·05	13·28	0·98	3·21
18th "	5·30	17·38	0·89	2·91
19th "	4·00	13·12	0·82	2·68
20th "	4·54	14·89	0·75	2·46
21st "	5·50	18·04	0·68	2·23
22nd "	5·10	16·72	0·61	2·00
23rd "	6·65	21·81	0·53	1·73
24th "	6·01	19·71	0·46	1·50
25th "	6·40	20·99	0·39	1·27
26th "	5·28	17·31	0·32	1·04
27th "	6·70	21·9(cap.)	0·25	0·82

The foundation, base, and a height of 13 metres (42·64 feet) of the circular shaft were built in the autumn of 1884, with scaffolding on the outside. The works were then stopped on account of the autumn storms. The other portion of the shaft was commenced on the 14th of April, 1885, and finished on the 19th of September in the same year. During this time the weather was very unfavourable, there being only one hundred and seven working days, in which time a height of 108·1 metres (354·56 feet) of the shaft was erected by an internal scaffold. The daily rise of the shaft was 0·6 metre to 2·0 metres (1·96 foot to 6·56 feet) according to the thickness of the wall and the state of the weather; no working day was lost to allow for the hardening of the mortar. The average number of men employed daily on the scaffold in the construction of the shaft was eight. The materials for the erection of the shaft were raised through the internal scaffold in a bucket having a capacity of ½ cubic metre (17·65 cubic feet) by a small locomotive engine, which ran on a line of rails starting from the bottom of the shaft. The whole of the

masonry and brickwork throughout the shaft is built in lime-mortar mixed with good sharp sand, with an addition (decreasing from the bottom to the top) of 12 per cent. to 10 per cent. of Portland cement.

The internal scaffolding was of the nature of a shaft, and was carried up some 30 feet in advance of the brickwork, for the convenience of hauling up the materials and moving up the bricklayers' scaffolding as the brickwork progressed. Inside this scaffold-shaft, or framing, was the bricklayers' scaffolding, which was fixed to the scaffold-shaft, and occupied about eight men in its erection for one hour per day. Up to the present the shaft is perfectly sound, and no iron hooping has been required. The shaft is provided with an efficient lightning conductor.

The weight of the whole structure, including the foundation, is 5,512,650 kilos (12,127,830 lbs. = 5,459·3 tons), and taking the area of the outside of the foundations as 146 square metres (1,570·96 square feet) (12 × 12 metres + 2 square metres for the projecting buttresses), the load per square metre on the rock foundation is equal to 37,757 kilos (8,306·5 lbs. per square foot) = 3·7 tons per square foot). The pressure per square foot at the top of the base of the stalk, where the circular work commences, is 9·61 tons. The height of shaft from the ground-line is thirteen times the diameter at the ground-line.

In calculating the stability of the shaft to resist the pressure of wind, a pressure of 783 kilos per square metre, or 160·38 lbs. per square foot, has been assumed. In working out this calculation for the bed-joint at the base of the stalk, the relation of the moment of stability to the moment of pressure of wind is such that they balance about the extreme outer edge of the shaft. This leaves no factor of safety with a wind-pressure of 160·38 lbs. per square foot. Notwithstanding this result, it will be seen that the shaft has ample stability when it is considered how great the wind-pressure has been assumed to be; a quantity nearly three times greater than that assumed by Professor Rankine and the English Board of Trade. The Author is of opinion that had this shaft been built in England, the conditions of construction would have been somewhat different. In the first place, the mortar would have been made entirely of Portland cement, or blue-lias lime, not mixed together, as described. Secondly, the shaft would have been so designed that the pressure per square foot on the rock foundation would have been reduced; also, the large pressure of 9·61 tons per square foot at the bed-joint, where the circular work commences, could have been considerably lessened by in-

creasing the size of the base, thereby increasing the stability. The Author thinks that had this shaft been built with a "hollow batter," or logarithmic line, its appearance would have been improved. The vibration of the shaft at the top is small.

For a great portion of this information the Author is indebted to Mr. Julius Matton, of the Mechernich Lead-Mining Company.

(*Paper No. 2168.*)

"Footpaths."

By Henry Percy Boulnois, M. Inst. C.E.

Much has been written upon the subject of roadways, but hitherto very little upon footpaths.

The Romans, who were the earliest road-makers, did not provide footpaths, for Bergier, in his "Histoire des Grands Chemins de l'Empire Romain," says that these roads had only blocks of stone at the side for foot travellers to rest upon. It is probable, therefore, that the addition of footwalks to the sides of roadways was by means of a gradual development.

As to the proportionate width of the footpath and carriageway, the Local Government Board has decided that the carriageway of every new street shall be 24 feet in width at the least, and that there shall be a footpath on each side of the street "of a width not less than one-sixth of the entire width of such street."[1]

By this rule it will be seen that the footpath has to be not less than 4 feet in width, and with regard to the roadway it should be if possible some multiple of 8, as 8 feet is the allowance of width which it is necessary to provide for vehicles passing each other at a rapid rate. The gutter, water-table, or channel, is part of the carriageway and thus has nothing to with "footpaths"; a few words about the kerb are, however, necessary.

The model byelaws referred to provide that the footpath shall be constructed "so that the height of the kerb or outer edge of such footway above the channel of the carriageway (except in the case of crossings paved or otherwise formed for the use of foot-passengers) shall be not less than 3 inches at the highest part of such channel, and not more than 7 inches at the lowest part of such channel." A height of less than 3 inches would render it possible for vehicles to drive on the footpaths, or for the water in the channel to overflow it; with a height of more than 7 inches the kerb would probably not remain upright but be forced out towards the channel.

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[1] "Model byelaws issued by the Local Government Board for the use of sanitary authorities. IV. New streets and buildings," p. 10, 1877.

Where there is much traffic granite is the most economical material for the kerb of a footpath, which is subjected to severe blows as well as to a grinding action from passing vehicles.

Setting granite kerb correctly is by no means an easy operation; it is heavy to handle, and has a tendency, if not well bedded, to sink, turn slightly over, or move out of place. The slightest inequality is easily detected, and is a prominent and objectionable blemish. Deep and narrow kerbs may be bedded on clean dry shingle or ballast, and must be beaten into place with a maul of about 50 lbs. in weight, and then well packed or rammed on both sides with an iron bar. Broad and shallow kerb must be placed on a concrete bed of sufficient breadth and depth to carry the weight. In no case is it well to have a kerb of less than 6 inches in breadth or of less depth than 9 inches, nor should the stones be less than 3 feet in length. The top face of kerb which is broader than 9 inches should be bevelled off so as to conform with the cross fall of the surface of the footpath. Clean sharp arrises on both sides are essential with stone kerb; the top face also should have a neat drafted edge about an inch wide all round it.

The material for the pavement should not be slippery upon the surface, and it should not scale nor flake; it should be durable, and not easily abrade; it should be strong, of equal quality, and be impervious to moisture; it should dry rapidly after rain and neither dirt nor dust should easily adhere to it; and above all it should be economical where efficiency is not sacrificed. Its absorbent powers may be tested by soaking in water and noticing the difference in weight; its microscopic appearance and specific gravity will give some idea of its quality; the wear may be ascertained by rubbing and drilling with certain defined and regulated pressures; but these observations are not to be compared with the experience gained by actual trial, and consequently the best test is to lay some of the proposed material upon a footpath where there is a known amount of traffic, and to note the wear after a certain time.

In this country the materials principally used for paving footpaths may be thus classified:—(1) Natural stones. (2) Natural asphalts. (3) Artificial asphalts and concretes. (4) Bricks. (5) Gravel and stone chippings.

(1) Natural Stones.

Of the natural stones, granite slabs are occasionally employed, but the stones most frequently used are either Yorkshire or Caithness flags. Limestones from various districts are also employed, and occasionally slate. With regard to some of these, granite, although it is exceedingly durable, is costly and expensive. In addition to this, it wears very slippery in course of time, and is also difficult to work. Outside market-places or public buildings, where the traffic is considerable, it may sometimes be adopted with advantage; but from returns which the Author obtained on the subject of paving footpaths from one hundred and thirty-eight English towns, in only eight of them is granite used to any extent for this purpose, whereas it is almost universally used for kerb. Yorkshire flags, on the contrary, comply with a great many of the essentials of a good footpath; they give a better foothold to the pedestrian than any other description of pavement, and no fewer than eighty-three of the towns largely employ it for footpaths. It is an economical pavement, as it is readily taken up, redressed, and relaid when partially worn out; it never wears slippery, and it is easily worked to curves, uneven frontages, or to coal-plates. Repairs are promptly and easily effected after disturbance of the footpath. In appearance it is cheerful, yet without glare or reflection of the rays of the sun, and the stones are of fairly large size. Not more than fourteen pieces should go to make up 100 square feet when laid. Each flag must be evenly bedded on a foundation of dry gravel or brick rubbish, set with blue-lias or cement mortar, the joints being properly butted together and well flushed up. These remarks apply to all foot-pavements, as they are dependent upon good foundations and good workmanship to secure a successful result. The disadvantages of Yorkshire flags as a material for paving footpaths are that their first cost is sometimes rather high; their liability to break when heavy goods are thrown upon them; their uneven wear; their absorption of moisture; their liability to tilt if not properly bedded; and their tendency to laminate as the effect of severe frost.

In Bradford, Yorkshire flags can be laid at 3*s.* 6*d.*, whilst in Battersea the cost is 11*s.* 3*d.*, per square yard. In Harrogate, Yorkshire flags are stated to last for twenty-five years, whilst in Leicester six or seven years is said to be their maximum duration of life. Some Yorkshire flags which had been laid in Lombard Street, in the City of London, in 1828, were taken up in 1846,

completely worn out, and were reckoned to have cost 1*s.* 3*d.* per square yard per annum in repairs during that period. The average cost of repairs in seven streets in the City was 1*d.* per square yard per annum, the cost for repairs in streets of little traffic being very small. In 1883 Mr. Lovegrove, the Surveyor of the Hackney district, reported that flags laid in 1857 had worn from $1\frac{1}{2}$ inch to $1\frac{1}{8}$ inch by 1883, and that those laid in 1864 had worn from $\frac{7}{8}$-inch to 1 inch.

In Wisbeach, flags have lasted for thirty years, and have then been used on edge for crossings. In Kennington, after being down for twenty-five years, they have been taken up and relaid in second-class streets, where they have remained for another twenty years, and have then been used on edge for crossings.[1] In Westminster they are reported as wearing rather rapidly in narrow footpaths. In the Strand some Yorkshire flags laid in the year 1861 were subjected to a daily average pedestrian traffic of 46,000 persons, and were thoroughly worn out in the year 1884; and it may therefore be assumed that this description of pavement wears at the rate of about $\frac{1}{16}$-inch for every 9,000,000 of passengers.

Many of the above remarks apply with equal force to other descriptions of natural stones. Most of the free-stones are of too soft a character to be used outside the districts in which they are quarried, and some of the limestones are very brittle, and wear slippery. Slate wears excessively slippery, so much so that even the Surveyor of Bangor prefers York flagging as a foot-pavement. The only natural stone that can compete with York flagging is Caithness stone, from Thurso, in Scotland, which seems to be daily gaining in favour as a material for footpaths. Twenty-three out of the one hundred and thirty-eight towns from which returns were received use this description of stone. Amongst other advantages, it is said to have a remarkably good appearance; it is impervious to moisture, does not wear slippery, nor scale, nor flake; it dries rapidly after rain, and is easily kept clean; it is most durable in wear, frost has no effect upon it; besides which it wears evenly, and it is powerful enough to resist the shocks of heavy goods thrown upon it, or the weight of vehicles if accidentally driven over it. In Birmingham, Caithness stone is considered to be the best material for paving footpaths, and Mr. Ellice-Clark, of Hove, is of opinion that it is superior to any other

[1] "Answers to questions upon the subject of pavings sent by the Metropolitan Sanitary Commission." W. Haywood, 1848.

description of flag-stone. In Devonport it has been laid for ten years without signs of wear. In South Shields some flags, which had been down in one of the principal streets for fifteen years, were taken up and sold at half their original cost, and in Sunderland some have been laid for upwards of twenty-five years in the main streets without being worn out.

The cost of this description of pavement is about 6*s.* or 7*s.* per square yard.

(2) Natural Asphalt.

A very complete description of Asphalt has been given in the Minutes of Proceedings,[1] but it may be well to state shortly that it is a natural limestone, intimately impregnated with mineral bitumen in variable proportions. The rock best suited for footpaths should contain about 7 per cent. of bitumen, and where possible none but the "compressed" method should be adopted where there is much traffic, the "mastic" being alone suitable for broad paths of light traffic. In no case should the former be laid less than 1 inch in thickness, nor the latter less than ½ inch in thickness. In both cases it is essential that a good foundation of cement concrete at least 3 inches in thickness should be provided, as asphalt being like a mineral leather, or elastic skin, has no strength in itself, but acts solely as a cover to the concrete underneath, which is thus the actual carrier of the traffic.

In many towns genuine asphalt is employed as a paving material for footwalks. It is almost impervious to moisture, and having no joints it is the best pavement that can be used from a sanitary point of view, and should always be employed if possible for courts and alleys, and where cleanliness is important. Asphalt can be expeditiously laid or repaired, with very little interference to the traffic. It requires less crossfall than other pavements, and it absorbs and does not radiate the heat of the sun. When once worn out, however, it cannot be used again like natural stone pavements. In Birmingham, it requires relaying every five or six years, and in Hove, neither the compound nor mastic asphalts have proved very durable. On the other hand compressed asphalt paths laid in some of the busiest thoroughfares of London have lasted ten years; and in Leicester, some mastic paths, costing 4*s.* 10*d.* per square yard, which were laid by the Val de Travers

[1] Minutes of Proceedings Inst. C.E. vol. xliii. p. 276, and vol. lx. p. 249.

Company in 1873, are only just wearing out. The best compressed asphalt, laid 1 inch in thickness upon footpaths subjected to a considerable traffic will last for ten or twelve years.

(3) Artificial Asphalt and Concretes.

Under this title may be included all descriptions of spurious asphalts, tar pavements, and concrete or artificial stone pavements. Owing to the knowledge that genuine asphalt is composed of limestone and bitumen, many attempts have been made to imitate it, one of the first being a compound of the following ingredients:

Material.	Proportions.
Waste products of tar-oil	50
Caustic lime	20
Pitch	200
Sawdust	30
Iron slag, grit, or chalk	700
Total	1,000

The materials were simply mixed, spread upon the footpaths, and rolled in layers of suitable thickness. Artificial asphalts were known for some time under different names, of which "Prentice's Mineral Foreign Rock Asphalt," and "Mendip Mountain Machine-made Asphalt," may be taken as examples, but such artificial productions are more correctly described as "tar concrete," or "tar paving." One of the earliest, known as "Lord Stanhope's Composition," which was laid in London in 1840, was made in the following manner:—

Material.	Quantities.
Stockholm tar	3 gallons.
Chalk	2 bushels.
Clean sharp sand	1 bushel.

These were boiled together in large cauldrons, and spread to the thickness required whilst hot.

The following is a description of one of the best systems of modern tar pavement:—Either gravel or stone chippings must be carefully screened through sieves of 1¼-inch, ¾-inch, ½-inch, and ¼-inch gauge, and then heated on iron plates with fires burning underneath. The gravel, or chippings, having been thoroughly dried and heated, the following ingredients are mixed together, boiled in iron cauldrons, and added whilst hot; 12 gallons of tar, ½ cwt. of pitch, and 2 gallons of creosote to about 1 ton of the screened materials. The composition when added to the gravel, or chippings, should spread easily and thoroughly over

every particle of the stone. This now becomes tar-concrete, and can be laid in layers, the largest size gravel at the bottom, and so on up to the smallest size, for the top layer, each layer as it is laid being well rolled with an iron roller of about 10 cwt.

In order to secure success with this description of pavement it is well to observe the following conditions:—The stone-chippings, or gravel, must be thoroughly heated so as to ensure perfect dryness, as then the composition will adhere firmly. It is better to keep the tarred materials a month or two before use, so as to be thoroughly soaked by the composition. Broken Kentish rag stone, or limestone chippings, make the best tar-pavements, as too hard a material causes a bumpy path. The laying should, if possible, be carried out in the spring, or winter, if dry, as a hot sun draws the composition away from the stone on to the surface of the path. The foundation of the path must be dry, as water seriously affects the tar-concrete. When the last layer of the path has been completed it must be dusted over with fine grit, or stone dust, and this facing, accompanied by a thin "painting" with tar, should be repeated at least once every other year.

At Banbury, the cost of tar-pavement is only 9*d.* a square yard, whilst at Hereford it is 3*s.* In Bath the cost is 1*s.* 9*d.*, and the footpaths last in good repair for twenty years; whilst in Burnley their life is only five years. In Darlington they last for ten years, and are then re-topped at a cost of 3*d.* per square yard, their original price having been 2*s.* per square yard. In Doncaster, where the cost is 1*s.* 8*d.* per square yard, the paths wear from twenty to thirty years. In Harwich, the cost being 1*s.* 4*d.*, they last ten to twelve years, a coating of hot tar and sharp grit being put on the surface every year. In Ipswich the life is thirteen years; and in Peterborough, where the cost is only 1*s.* 3*d.* per square yard, the life is from fifteen to twenty years. In Scarborough the cost is 1*s.*, and the life ten to fifteen years; and in Windsor, the cost is 2*s.*, and the life twenty years. In Streatham it is used in all new streets previous to being taken over by the local authorities, and some paths laid down in the year 1870 remained perfectly sound and good at the end of the year 1885. The disadvantages of tar-pavement are as follow:—It is dark in colour unless a very light-coloured stone chipping is used; it is apt to wear gritty or bumpy; it is rather difficult to repair. In very hot weather it sometimes becomes rather sticky or soft. Tar-pavement must only be reckoned as a substitute for ordinary gravelled footpaths. It must not be compared with paved or asphalted paths; and in no case in the

returns to which allusion has been made is tar-pavement the only material used on the paths. But to show how popular this material has become, no less than sixty-four towns successfully employ it for suburban foot-paths.

Footpaths of Portland-cement concrete are gradually gaining in favour, and this material may be looked upon as the pavement of the future. Recently a considerable number of towns have introduced monolithic pavements of concrete with very satisfactory results. At first, on laying concrete in mass with large exposed surfaces great alterations took place on changes of temperature, and the concrete either cracked or gaped, or rose up from its bed into arches and curves. The cure for this has been to lay the concrete in widths of about 6 feet, completing each width alternately, and allowing the intermediate width to set for a day or two before the neighbouring one is commenced. Also by leaving laths or strips of wood between the widths of concrete, and subdividing these widths by cutting into the concrete with a trowel before it is set, thus splitting the mass of concrete and giving it plenty of room to expand. Shingle or gravel does not produce a good surface for a concrete path, the particles are too round; they either protrude, or are dislodged leaving holes, and the surface soon breaks up or becomes slippery. Crushed granite makes a good face to a concrete path. The following proportions of materials are given for a path subjected to considerable wear:—Bottom layer 2½ inches thick, composed of 1 part of Portland cement to 6 parts of clean sharp shingle, gravel, or broken stone; upper layer ½ inch thick composed of 1 part of Portland cement to 2 parts of finely broken and well-washed granite. In mixing the materials the greatest care must be exercised. The best Portland cement, the cleanest and sharpest shingle and stone, a proper amount of water, and perfect mixing and incorporation of the materials upon a clean bunker, are necessary; and finally the concrete must receive a proper amount of ramming and skilful trowelling up of the surface.

Traffic should be prevented on concrete footpaths until the concrete is thoroughly set, either by diverting it, or by covering the footpath with boarding for about a fortnight. Even after this lapse of time it is as well to lay wet sand on the path, so as to keep the traffic off for a longer period, since until the concrete is properly matured it will not withstand the rubbing effect of the traffic. This description of pavement has also the objection of being rather slippery on an incline, and it thus becomes necessary to give less cross-fall than other pavements. It has also the disadvantage of

not being easily repaired, and there is a risk of failure if not most carefully carried out. When worn out it is useless. Notwithstanding these disadvantages, it is so cheap to manufacture, of so excellent an appearance, and so durable, that it is to be much recommended where the inconvenience to the traffic or occupiers of neighbouring shops need not be considered. Where these matters have to be taken into account, concrete slabs or flags can be substituted for monolithic concrete; they can be laid even more rapidly than natural stones, as they are of uniform size, and consequently require very little handling. These slabs are usually made about 2 inches in thickness; they consist of concrete, well rammed into wooden moulds lined with iron. When sufficiently set, the moulds are taken to pieces, and the slabs may then be placed in a bath, or stacked in the open air until thoroughly matured. This description of pavement is exceedingly cheap, especially where good shingle is easily obtainable; the blocks are of uniform size, and consequently give an evenness of the break-joint; and the joint itself is very narrow; the slabs are of a pleasant grey colour, they wear perfectly evenly, and are indifferent to changes of temperature; they are easily kept clean, and dry rapidly after rain; and if properly and securely bedded are fairly strong to resist shocks. When one surface is worn, they can be turned, though of course the under-side is not so durable as the upper; still, from the long period during which they have matured whilst the upper surface has been wearing, there is considerable life in the lower surface, which is suitable for streets of lighter traffic. This pavement can be manufactured and laid down for about 3*s.* per square yard, and its life may be considered as exceeding that of Yorkshire flagging.

(4) Bricks.

Ordinary bricks were no doubt formerly used for paving footwalks in some districts, because no better material could be procured except at a prohibitive price; eventually hard vitrified stoneware bricks were introduced in Staffordshire, with a chequered or diamond-pattern surface, and these bricks have been extensively used ever since, principally on account of their cheapness and durability. In West Bromwich, for instance, a pavement of this description only costs about 1*s.* 9*d.* per square yard, and has a life of upwards of thirty years. In Derby these bricks last for twenty years, and can then be used again for other purposes; and generally they have been excessively durable when thoroughly vitrified;

they are especially suitable for use in back-streets or narrow footpaths in the districts in which they are manufactured. They have, however, a multiplicity of joints, and the pavement cannot therefore be considered a sanitary one; they are difficult to bed level unless laid upon a foundation of concrete, which adds largely to the cost; they wear very slippery and unevenly, and unless the quality is of the best, the skin is soon rubbed off, showing a red interior which wears as rapidly as an ordinary building-brick. A thoroughly satisfactory pavement of this material is not easily obtainable; the appearance of the bricks is against them, and a brick pavement always feels "harsh" to the feet. A buff brick of an improved appearance has lately been introduced, and is said to wear as well as the blue vitrified Staffordshire brick.

(5.) Gravel and Stone Chippings.

Very little can be said upon this subject; such footpaths are only suitable for suburban districts, or opposite vacant land; they are uncomfortable to the pedestrian, and are either covered with loose stones and dust in dry weather, or with slippery mud in wet weather. In Chorley, screened furnace cinders are used instead of gravel, at a cost of 4*d*. per square yard, and the footpaths last for about eighteen months without repair. Chippings of Mendip rock, limestone, and even of granite, are sometimes substituted for gravel with good results, but these footpaths cannot be considered economical, as the material of which they are made is constantly being washed or kicked off the path; and it was to meet the unsatisfactory state of things arising from the "gravelled" path that tar-cement was introduced with such beneficial results.

In conclusion, it may be well to note briefly, that Yorkshire flagging has for years, especially in the metropolis, held its own as a natural stone pavement. Asphalt has suffered in repute from inferior materials having been used under that name. Tar-pavement is an excellent substitute for gravel paths, and is a good pavement for light traffic. Concrete-monolithic and flagged footpaths are every day gaining in favour, and have much to recommend them; and gravelled paths are only suitable for country or suburban districts, as they are most uncomfortable to walk upon.

(*Paper No. 1942.*)

"The Separation of Galena and Blende from their gangue as practised at the Mines of Sentein, Ariège, France."

By Ernest du Bois Lukis, Assoc. M. Inst. C.E.

This is a record of detailed observations made whilst preparing for market galena and blende, at the mines of Sentein in the Pyrenees. The ores were intimately mixed in the proportion of 8 to 10 per cent. of galena, 15 to 20 per cent. of blende, and gangue consisting of hard quartz, quartzose rock, schist, &c. The market lead-ore obtained included from 16 to 20 oz. of silver per ton. The blende did not contain sufficient silver for valuation. By experiments in the laboratory, it was found that the galena lost very little silver by fine crushing and washing.

The machinery, supplied by Mr. George Green, of Aberystwyth, was erected in existing buildings; but these were so scattered that it is not thought necessary to give a plan of them. Instead of this, a method of arranging the whole of the required plant under one roof, with slight modifications, that would render such proposed dressing-floors more efficient, is given in Plate 7, Figs. 1, the substantial structure indicated being necessary on account of the climate of the Pyrenees, where protection from frost and snow is indispensable.

Water-power was used, being abundant, but the motors are not shown in Figs. 1, for, depending on the position of such proposed floors, steam or water would be used as might be found most advantageous. Mention is, however, made later on of the power required.

The first point of importance is to size the ore-stuff; that is, when it has been crushed, particles of equal volume must be collected together, in order that they may be treated separately. For this purpose, riddles and classifers are used, and the ores of various sizes are treated by different machines, whether jiggers or buddles.[1] The operations should be so conducted as to separate the marketable minerals in as large grains as possible. The reduction

[1] "The Dressing of Lead Ores." By Thomas Sopwith, Jun., M. Inst. C.E. Min. Proc. Inst. C.E. vol. xxx. p. 106.

to absolute fineness should be gradual, and intermediate dressing operations resorted to, for the finer the particles through subdivision the more difficult and costly become the dressing operations, and the greater the loss of minerals. In the present case the ore-stuff is crushed to pass through a riddle having square holes of 4½ millimetres (0·18 inch).

Jiggers are used as far as possible to separate the minerals from their gangue, as they entail only one-tenth the cost of buddle-work, as regards labour, and less loss of mineral. Ore-stuff that would pass through a riddle, with holes ½ millimetre (0·02 inch) in diameter, could be jigged perfectly well, if freed from slimes. Ore-stuff that cannot be jigged is divided into two classes, "fines" and "slimes," and is dressed by buddling. The rich "heads" of buddles, when concentrated to about 60 per cent. of metallic lead for galena, or blende of about 42 per cent. of metallic zinc, are worked by tossing and packing in a kieve or dolly, so as to obtain marketable ores of about 69 per cent. Pb, and 48 per cent. Zn respectively.

This operation of ore-dressing, briefly alluded to, is divided into eight sections: (1) Picking for Prills; (2) Breaking and crushing; (3) Sizing and classifying; (4) Jigging; (5) Buddling; (6) Recrushing, pulverizing, and dressing chatts; (7) Dollying, or tossing and working the flat-buddle; and (8) Treating and collecting slimes.

1. *Picking for Prills.*—At the Sentein mines the ores were too intimately mixed to render picking of practical value; but at many mines, especially those whose ores are rich in silver, this process is most serviceable, and is therefore mentioned here. The ore-stuff is tipped in to a large masonry hopper, A, Plate 7, Figs. 1, at the bottom of which cast-iron plates, B, are placed, and a revolving picking-table might be also used. The ore-stuff is washed by a jet of water from a hose, enabling the workmen to quickly distinguish and pick out the prills or pieces of virgin galena or blende, as they rake the ore over the plates towards the grating, W. The plates, B, are so arranged as to allow the water to run off into a launder below, carrying with it fine particles of ore and slimes. This water passes through the double trommel, E, and thence to the dressing-floors, where its contents are treated. The prills being put to one side are again picked over before sampling for market.

2. *Breaking and crushing.*—The ore-stuff is next raked over the grating, W, made of flat-iron bars, 3 inches deep and ½ inch thick, set on edge 4 centimetres (1·57 inch) apart. The ore that passes

between these bars is conducted by a launder, in which water flows, to the double trommel, E, Plate 7, Figs. 1. This double trommel has an inner sieve, with holes 2 centimetres (0·79 inch) square, and an outer sieve, with holes $4\frac{1}{2}$ millimetres (0·18 inch) square. The inner sieve is merely to protect the outer sieve from unnecessary wear. The ore that will not pass through the outer sieve is conducted in a launder to the crushing-rolls, D. The fine stuff that passes through the outer sieve goes at once to the dressing-floors.

The rock and stones that remain on the grating, W, are put into the stone-breakers, C_1, C_2, where they are broken into fragments that will pass through a ring 4 centimetres (1·57 inch) in diameter. These fragments also go into the double trommel with the small stuff that has passed through the grating, the fine ore-stuff going to the dressing-floors, the coarse to the crushing-rolls. The stone-breakers at Sentein are of two sizes. The smaller one, C_1, for medium-sized stones, has a mouth 25 centimetres (9·84 inches) long by 15 centimetres (5·91 inches) wide. The larger one, C_2, for large stones, has a mouth 50 centimetres (19·68 inches) by 25 centimetres (9·84 inches). The faces of the jaws are of cast-iron, chilled to a depth of 3 centimetres (1·18 inch); the wearing edges of the toggles, and the bearings in which they work, are also chilled. Only two such stone-breakers were used at Sentein, but they were insufficient for the work. The large stone-breaker was driven by belting from a water-wheel, 14 feet in diameter and 3 feet breast, and it often had to be worked day and night to keep one-half of the floors supplied with ore-stuff during the day. With an additional pair of stone-breakers, such dressing-floors would be amply supplied with ore-stuff.

The quantity of stuff that may be crushed by rolls in any given time depends upon the size to which the ore-stuff has been first reduced by the stone-breakers, and it was found that the fragments should be able to pass through a ring from 4 to 5 centimetres (1·57 to 1·97 inch) in diameter.

The crushing-rolls at Sentein were three in number, one 61 centimetres (24·02 inches) in diameter by 40·5 centimetres (15·95 inches) wide, and two others, each 38 centimetres (14·96 inches) in diameter by 33 centimetres (12·99 inches) wide. It was found that, with the assistance of the small stone-breaker, the large rolls could do nearly as much work as the two small ones, one of which was assisted by the large stone-breaker.

In the proposed dressing-floors (Plate 7, Figs. 1) rolls 68 centimetres (26·77 inches) in diameter by 46 centimetres (18·11

inches) in width are designated as being more efficient. These rolls consist of three parts: the shafting, 15 centimetres (5·91 inches) square, of wrought-iron; the core, which should be well keyed on to the shafting and the same width as the roll, is of cast-iron, not chilled; and the ring, of cast-iron, with the face chilled to a depth of 3 centimetres (1·18 inch), about 8 centimetres (3·15 inches) thick, with grooves 2 centimetres (0·79 inch) deep and 2 centimetres (0·79 inch) in width diagonally across the face, half way across; six grooves in one half, alternating with six grooves in the other half of the face. These grooves do not continue to the edge of the face, but to within 3 centimetres (1·18 inch) of it. The core is made about 3 centimetres (1·18 inch) less in diameter than the inside diameter of the ring, so that the space between may be wedged up with dry deal wedges, driven in from both sides, which are then keyed up with small soft iron wedges. To keep the rolls tightly pressed together when working, levers and a balance-box were found to answer better than springs or india-rubber. India-rubber cushions soon deteriorate, and workmen do not pay enough attention to them. The rolls worked better when only one roll was connected with the driving-shaft, the second roll working by friction on the first. By adopting this method more work was done than when either equal or differential gearing connected the two rolls, and less driving-power was required. The driving-roll made 10 revolutions per minute to 8 revolutions of the second roll, and consequently wore away faster; but by occasionally changing the relative positions of the rolls, the ill-effects of unequal wear were obviated. The speed of the driving-rolls at the periphery is about 60 feet per minute. The ring lasted from five to six months, working six days per week.

The crushed ore-stuff is conducted by a launder below the rolls to the riddle J, covered with sieving having holes 4½ millimetres (0·18 inch) square, equal to circular holes about 5 millimetres (0·20 inch) in diameter. The stuff passing through goes to the dressing-floors; the coarser grains are returned to the crushing-rolls by the elevator V V. This elevator consists of an india-rubber belt 15 centimetres (5·91 inches) wide and 1 centimetre (0·39 inch) thick, passing over and under two pulleys, fixed at different levels. The top pulley is worked by a small toothed wheel and pinion. Small buckets are bolted on to the belting, at intervals of about 1·50 metre (4·92 feet), which take up the ore and discharge it at the upper level as they turn over the top pulley. The elevator is inclined at about 80° with the horizontal plane.

3. *Sizing and Classifying.*—The ore-stuff having been crushed

small enough to pass through the sieve J (Plate 7, Figs. 1) consists of particles of all sizes, from fine dust to the largest grains that could pass through the sieve.

To permit the separation of the particles of different densities by dressing operations, those of equal volume must be collected together, and others eliminated as much as possible, by mechanical means. To do this, riddles and classifiers are used. The riddles, F_1 to F_3, are cylindrical, and covered with copper plates, pierced with circular holes of varying diameters, and they make 10 revolutions per minute. The first riddle, F_1, has holes 4 millimetres (0·16 inch) in diameter; the second, F_2, holes 3 millimetres (0·12 inch); and the third, F_3, holes 2 millimetres (0·08 inch) in diameter. The first is 2·20 metres (7·22 feet) long, the second and third are 1·90 metre (6·23 feet). All three are 60 centimetres (23·62 inches) in diameter.

The first classifier or spitzkasten, F_4 (Plate 7, Figs. 2 *a*, *b*, *c*), has a depth of 15 centimetres (5·91 inches) below the level of the bottom of the launder; the second, F_5 (Plate 7, Figs. 3 *a*, *b*, *c*), a depth of 20 centimetres (7·87 inches); the third, F_6 (Plate 7, Figs. 4 *a*, *b*, *c*), a depth of 30 centimetres (11·81 inches), the inclined planes making an angle of 45° with the horizontal line. A pipe, of 2½ centimetres (0·98 inch) bore, enters the side of each classifier about 5 centimetres (1·97 inch) from the point, and is connected with a water-main of 7½ centimetres (2·95 inches) bore, under pressure of a head of water of about 2 metres (6·56 feet). The pressure to each classifier is regulated by a tap fitted to each small pipe. The large classifier, F_7 (Plate 7, Figs. 5 *a*, *b*, *c*), for slimes, is 3 metres (9·84 feet) in depth and 1 metre (3·28 feet) in width, the inclined planes making an angle of 60° with the horizontal line. A straight pipe, with a bore of 2½ centimetres (0·98 inch), fitted also with a tap, and connected with the water-main, passes down the centre, reaching nearly to the bottom. Holes are made in the small classifiers, in that side opposite to which the hydraulic pipe enters, which can be partly closed with wooden plugs, so as to regulate the feed of ore to the dressing-machines. A tap is fixed to the bottom of the large classifier, through which the thick slimes are drawn off and supplied by a launder to the buddles.

The principle upon which the action of these classifiers depends is as follows:—When particles of matter of varying densities are carried along by a stream of water in a launder, the heaviest flow in the stratum of water nearest the bottom; those of the next lower density in the stratum of water immediately above, and so

on. Further, when particles of varying densities are simultaneously immersed in a column of water, and allowed to subside freely, the heaviest reach the bottom first. Thus when the crushed ore-stuff is carried along the launder to the first classifier, both these principles come into action, and the heaviest particles can be drawn off from holes in the bottom of the classifier, while the lighter ones, further assisted by the upward flow of water from the hydraulic pipe, flow on to the second classifier, and so on.

The ore that does not pass through the first riddle consists of particles between 4 and 5 millimetres (0·16 and 0·20 inch) in diameter, and is supplied by a launder to the first jigger G_1 (Plate 7, Figs. 1); that not passing through the third riddle, between 3 and 4 millimetres (0·12 and 0·16 inch) in diameter, goes to the second jigger, G_2; that not passing through the third riddle, between 2 and 3 millimetres (0·08 and 0·12 inch) in diameter, goes to the third jigger, G_3. An iron trough, under each riddle, receives the stuff and conveys it to the classifiers which are fixed to that launder. On reaching the first, F_4, the heaviest and largest particles, from 1 millimetre (0·04 inch) to 2 millimetres (0·08 inch) in diameter, fall to the bottom, and are drawn off through the holes in the side to supply the fourth jigger, G_4; and the pressure of water in the small pipe connected with the bottom of the classifier is so regulated that the whole of the slimes, with much fine stuff, rise and flow on to the second classifier, F_5, where the same action is repeated, no slimes being allowed to reach the fifth jigger G_5, which takes stuff from about ½ to 1 millimetre (0·02 to 0·04 inch) in diameter. The third classifier F_6, in the same way supplies "fines" to the first buddle H_1, with but little slimes. The water in the launder, now charged with only very fine ore-stuff and slimes, passes over a straight-edge for the whole width of the large classifier F_7, and under the board X, Plate 7, Figs. 5 *a*. The liquid from the bottom flows through the tap Y to the buddle H_2, and, as the water becomes free from muddy matter suspended in it, rises to the surface, and, flowing over another straight-edge in a thin film almost clear and limpid, is used to work a wheel I, 3 metres (9·84 feet) in diameter and of 50 centimetres (19·68 inches) breast, and supplies the motive force for the buddles. The holes in the riddles are kept clean by a spray of water, under pressure, from a perforated pipe which plays upon them from the outside along their whole length.

4. *Jigging.*—The jiggers are five in number, each consisting of four compartments; the compartment or hutch is equally divided into a jigger-case and a piston-case, Plate 8, Figs. 13, 14, 15.

They are made of pine deals 75 millimetres (2·95 inches) in thickness, laid on a keel, Plate 8, Fig. 19; all longitudinal joints are tongued with dry oak $2\frac{1}{2}$ centimetres (0·98 inch) by 1 centimetre (0·04 inch). The structure is fastened together by five $1\frac{1}{2}$-centimetre (0·59 inch) bolts vertically through the cross-heads of cast-iron, Figs. 21 *a b*, and across by bolts A A, Fig. 18, passing through the divisions.

The cases thus made are supported on stands, Plate 8, Figs. 23 and 24, *a*, *b*, *c*, to which the shafting-stands are fastened by two bolts. Light rods are bolted between the stands near the head, through holes X X. A turned shaft 44 millimetres (1·73 inch) in diameter runs through the stand-heads working in brasses well lubricated. On to this shafting the eccentrics are keyed, so that the piston-rod attached may be plumb over the centre of the piston-cases. The piston is shown in Plate 8, Figs. 18 *a*, *b*. Fast-and-loose pulleys are also put on the shafting in a convenient position for the belting from the driving-shafting.

The sieves or bottoms of the jiggers are put on a grating of cast-iron, Figs. 16 *a*, *b*, which rests on planking screwed on all round the jigger-case. A similar grating over the sieve is kept in place by planking screwed on in the same manner as that below, but with copper screws to facilitate changing the jigger-bottoms.

Each compartment of the first jigger G_1 has a depth from the lip at the overflow to the top of the sieve of 70 millimetres (2·76 inches); the compartments of the second jigger have a depth of 65 millimetres (2·56 inches); those of the third jigger of 60 millimetres (2·36 inches); those of the fourth jigger of 55 millimetres (2·17 inches); those of the fifth of 50 millimetres (1·97 inch).

The lip of each jigger-case has a fall of 2 centimetres (0·79 inch) from one compartment to another, and is covered with a cast-iron plate, Plate 8, Figs. 17, F, to prevent wear.

The eccentric, which drives the plungers of the jigger, Plate 8, Figs. 22 *a*, *b*, *c*, is made in three parts. One of these, shown in back elevation in Fig. 22 *b*, is keyed to the shaft, and has two bolts projecting from it; the others are the eccentric and eccentric-strap. A is the eccentric which can be moved laterally for the length of the slots Y Y *a*, through which pass the bolts of the fixed part *b*. These slots allow a displacement of the eccentric of 2 centimetres (0·79 inch) from the dead centre, which is equal to a stroke of 4 centimetres (1·57 inch) of the piston. By loosening the nuts on the bolts, and giving a slight blow to the side of the

eccentric, the distance from the dead centre to the centre of the eccentric will be slightly altered, which distance is equal to half the difference made in the length of the stroke of the piston. Thus, suppose the eccentric to be at the dead centre, by moving it 1 millimetre (0·04 inch) out of the centre a stroke of 2 millimetres (0·08 inch) is obtained.

Various experiments have been made to find a metal that will wear the least, of which the eccentric may be constructed, and close grained strong cast-iron has been found to answer as well as any thing, besides being cheapest. All working parts should be accurately fitted and well lubricated. The sieves are of copper plates punched with conical holes; the rough side is uppermost. The four compartments of the first jigger, G_1, have plates with holes $5\frac{1}{2}$ millimetres (0·22 inch) in diameter; those of the second jigger, G_2, holes of $4\frac{1}{2}$ millimetres (0·18 inch); those of the third, G_3, of $3\frac{1}{2}$ millimetres (0·14 inch); of the fourth, G_4, 3 millimetres (0·12 inch); and of the fifth, G_5, $2\frac{1}{2}$ millimetres (0·10 inch).

A valve, valve-rod, and lever, Plate 8, Figs. 20 *a*, *b*, *c*, complete the jigger, which is placed over a long trunk of deal 75 millimetres (2·95 inches) thick, having four compartments, corresponding with the four compartments of the jiggers. When the valve is raised the ore is received in these compartments, the overflowing water being conducted to the slime pits, &c.

To begin operations, a bedding of ore from 2 to 3 centimetres deep (0·79 to 1·18 inch), galena being used in the first compartment, is placed on the plates of the jigger, mixed galena and blende on the second, and blende on the plates of the remaining compartments. After some weeks' work chips from miners' drills accumulate on the bottoms of the jiggers, and form a better bedding than galena or blende, for these latter are too brittle. It would therefore be better to use small chippings from a fitting-shop, or disks from punched iron plate, to commence with. These should be a little larger than the holes in the bottoms of the jiggers so as not to pass through them.

The jiggers are filled with water from the tap X, Plate 8, Fig. 13, and the ore-stuff is supplied through launders from the several riddles and classifiers. At the bottom of each launder there should be a distributing-plate, Fig. 28 *a*, *b*, made of cast-iron, so that the ore may enter at the head of the first compartment without disturbing the bedding. This was not done at Sentein, where the want of it caused some inconvenience. As the ore-stuff is supplied, it travels onwards towards the out-flow at each stroke of the piston, assisted by a continual flow of water

supplied from the tap X; the heavy particles percolate through the sieves into the hutches below according to their densities. Thus galena passes into the first compartment; mixed galena and blende into the second, and blende into the third and fourth compartments, of each jigger. The waste passing over the lips of the fourth compartment is almost free from mineral. It may sometimes be necessary, in order to prevent loss of mineral in the waste, to allow a little gangue to remain in the fourth compartment with the blende.

The mixed ores of the second and fourth compartments of each jigger are again treated by separate machinery, being further crushed, sized, jigged, and buddled, &c., until the waste is free from mineral, and the galena and blende are ready for market. About 80 per cent. of all the ore-stuff is treated by jigging, the remainder goes to the buddles. The fourth jigger, however, does more than one-third of the work, and requires special attention. The results of the assays, as shown in the following Table, demonstrate where modifications should be made.

ASSAYS of RESULTING ORES in the HUTCHES.

Ore-Stuff. Average Sample.	1st Jigger.	2nd Jigger.	3rd Jigger.	4th Jigger.	5th Jigger.
Per cent. { 9½ Pb, 21 Zn	6 Pb, Zn ?	7½ Pb, Zn ?	9½ Pb, 20½ Zn	24½ Pb, Zn ?	6 Pb, 22¾ Zn
1st compartment or hutch . . .	Per cent. 67½ Pb	Per cent. 72 Pb	Per cent. 76 Pb	Per cent. 77¾ Pb	Per cent. 77¾ Pb
2nd " "	36½ Pb, 22½ Zn	49½ Pb, 17½ Zn	30½ Pb, 32 Zn	30½ Pb, 33 Zn	28 Pb, 36 Zn
3rd " "	7 Pb, 39½ Zn	9 Pb, 45 Zn	6½ Pb, 45 Zn	8 Pb, 44 Zn	7½ Pb, 45½ Zn
4th " "	6 Pb, 46 Zn	5 Pb, 50 Zn	6 Pb, 46 Zn	6½ Pb, 45 Zn	5 Pb, 48 Zn
Waste . . .	0 Pb, 12 Zn	0·3 Pb, 7½ Zn	0·5 Pb, 4½ Zn	0·7 Pb, 4 Zn	0 Pb, 4 Zn

The ore-stuff supplied from the crushers contained about 9½ per cent. Pb and 21 per cent. Zn; this being classified showed that the galena and blende, not being so hard as the gangue, were crushed finer than could have been wished, but it was not to be prevented. The first hutch of the first jigger only gave 67½ per cent. of lead, which was too low, and both the bedding and the

stroke had to be altered to improve the result, bedding being added and the length of the stroke being slightly diminished, as some grains of gangue percolated into the hutch. The blende was too rich in lead, so some bedding was taken out of the second compartments and more mixed ore was produced; this also assisted in diminishing the loss of blende, which, especially for the first jigger, was enormous. The results sought were to obtain galena containing 75 to 78 per cent. of metallic lead; with blende at 47 to 49 per cent. of metallic zinc; not more than 8 per cent. of metallic lead, and waste to contain not more than 0·5 per cent. of Pb, and 1 to 1½ per cent. Zn, and this was done. By frequently testing the resulting ores on a vanning shovel, and rubbing the samples very fine with a hammer, the relative percentages of lead and of blende can be easily ascertained. Such tests should be verified by assays, and a little practice will enable an ore-dresser to arrive at estimates within ½ per cent. of the truth in the case of lead. This more especially refers to the blende ores. If the proper result is not obtained, it must be sought by altering the length of stroke of the piston, and adding or removing some of the bedding on the jigger-bottoms.

The length of stroke of the piston should be just sufficient to lift the mineral on the surface of the bedding to a height equal to the diameter of the particles under treatment. Thus, for the first jigger, the grains of from 4 to 4½ millimetres (0·16 to 0·18 inch) (square sieve), need a stroke of about 9 millimetres (0·35 inch) to raise them to a height of from 4 to 4½ millimetres (0·16 to 0·18 inch); and in the fifth jigger it requires a stroke of about 3 millimetres (0·12 inch) to raise the grains a height of from ½ to 1 millimetre (0·02 to 0·04 inch). No rule can be given, but practice will soon show what length of stroke is necessary.

The number of strokes per minute of each piston is the next thing to attend to. The grains should be allowed sufficient time between each stroke to fall through a distance equal to their diameters; the strokes being given in quick succession allow the heaviest grains just to settle in the bedding when the next stroke further tends to free the descending particles from those of less density which surround them, and thus by degrees permit them to reach the plate and pass through into the hutch below. The number of strokes per minute for the first jigger should be about 200; for the second about 220; for the third from 240 to 250; for the fourth, from 260 to 270; and for the fifth jigger, from 280 to 300.

The ore should be frequently drawn off from the hutches to

allow sufficient space inside the cases for the proper working of the piston and the water. The galena is taken from the trunks below the jiggers to the flat-buddle, where it is freed from any slimes or fine blende, and then put to pile ready for market. The blende is ready for sampling without treatment on the flat buddle.

The loss of lead in the waste is accounted for by mere specks of galena on grains of gangue, and in the blende to the lamellar fractures which cannot be saved without more cost than profit.

5. *Buddling.*—The "fines" and "slimes" supplied by the classifiers (Plate 7, Fig. 1), F_6 F_7, are treated by round buddles. The first for very fine-grained stuff; the second for the slimes H_1 H_2.

These buddles are circular (Plate 7, Figs. 7, 8), 4·27 metres (14 feet) in diameter and 35½ centimetres (13·98 inches) in depth.

They are built of stone or brick, preferably the latter, and are well cemented. In the centre, the cone A (Plate 7, Fig. 9) of cast-iron, is placed on firm ground, two pieces of wood being bolted to the base. Small broken stones or bricks beaten down form a bottom on which a layer 5 centimetres (1·97 inch) thick, of a mixture of cement, hydraulic lime and sand, is evenly laid with an inclination of 5½ centimetres (2·17 inches) from the outer circumference of the cone to the inner circumference of the brick or stonework. The vertical shafting being fixed in position, a gauge is adjusted to it (Plate 7, Fig. 11), which being turned round the shafting, regulates both the circle of masonry and the level of the cemented bottom. The vertical shafting is turned 38 millimetres (1·50 inch) in diameter, and rests on a footstep, F (Fig. 9), which can be lubricated by a small hole in the cap, X. This hole is closed by a wooden plug when the buddle is at work, to prevent sand from running in. No brushes are used with these buddles, but a "hose" and a "rose" are substituted. The "hose," D (Fig. 9), is a zinc pipe of 5 centimetres (1·97 inch) bore, soldered on to an iron pipe that passes through the side of the centre-piece C, and is screwed to the perforated pipe H, shown in detail in *a* and *b* (Figs. 10). The zinc pipe is pierced with holes about 1 millimetre (0·04 inch) in diameter and 3 centimetres (1·18 inch) apart in three rows. A fourth row may be added if the ore under treatment needs much water. The "rose" is a cylinder of copper, E, Fig. 9, of 5 centimetres (1·97 inch) bore. It is screwed on a bent iron pipe of 2½ centimetres (0·98 inch) bore, and also passes through the side of the centre-piece opposite the "hose," and is screwed to the perforated pipe H. The hose and rose are sup-

plied with water through this perforated pipe from the trough above, B, Fig. 9, to which it is keyed. A continuous flow of water from a supply-pipe, X, Fig. 7, of $2\frac{1}{2}$ centimetres (0·98 inch) bore, fitted with a tap at Y, regulates the supply and keeps the requisite quantity in the trough. In using a cast-iron centre-cone with a smooth surface, runnels do not form in the ore-stuff in the buddle as is the case when wooden centre-cones are employed. The hose supplies water to the buddle, the supply increasing as the radius of the buddle from the cone to the circumference, and does excellent work even with very fine slimes, when the quantity of water used is properly regulated.

The ore-stuff is supplied by a launder to the centre-piece C, Fig. 9, and passes through the holes at the bottom to the cap, which distributes it evenly all round the cone as the shafting revolves. Layer by layer the ore-stuff covers the bottom of the buddle, the heavier particles remaining at the head, and the lighter ones being washed down the inclined plane to the tail. A small ring of water is kept at the tail of the buddle to prevent the ore from escaping with the water, and as the stuff rises in the buddle pieces of wood are placed in the slot Z, Fig. 7, to keep the water at the requisite level. When the deposit reaches the top of the cone the work is stopped, a groove is cut from head to tail with a shovel, and samples are taken, which must be crushed and washed on a vanning-shovel to judge where the divisions should be made; for at the head the ore is rich in galena, then follow two qualities of mixed ore of galena, blende and gangue, and lastly poor tailings. Rings are marked round, and the different qualities are taken away for further treatment in other buddles, $T_1 \ldots T_5$, Plate 7, Figs. 1. The heads, after being once reworked, will be ready to go to the dolly; but the mixed and the poor middles must be treated several times if the waste is to be made as free from mineral as possible.

The buddles $T_1 \ldots T_5$, are fed by hand. The ore is put into the trough of the mixing-machine (Plate 7, Figs. 6, *a*, *b*, *c*), each buddle being furnished with one, water is supplied by a pipe regulated by a tap, and as the mixing-machine revolves the ore passes through a sieve with holes $4\frac{1}{2}$ millimetres (0·18 inch) square to a launder and thence to the buddle. These buddles are of the same construction as those that have already been described, but they may be made a little larger, namely, 5·20 metres (17·06 feet) in diameter and 42 centimetres (16·54 inches) in depth.

The ore must be regularly supplied to ensure the proper working

of the buddles. When full these are emptied like the others, the different classes of ore being treated over again with other ores of approximate richness and size, until all the gangue is extracted, and the galena separated from the blende. The galena is enriched to between 50 to 60 per cent. Pb; the blende to about 42 per cent. Zn, and 3 per cent. Pb, and then tossed and packed in the dolly. The waste from the buddles contains between 0·25 and 0·5 per cent. Pb, and from 1 to 1·5 per cent. Zn.

The motive power for the buddles is furnished by a water-wheel I, driven by the overflow from the large classifiers F_7, O_4, Plate 7, Figs. 1.

6. *Re-crushing, pulverizing, and dressing chatts and ragging.*—The mixed product of the jiggers in the second and fourth compartments, called chatts or ragging, must be separately treated. The chatts from the first three jiggers are raised by the elevator K K, Plate 7, Figs. 1, and conducted at a higher level by a launder to a pair of crushing-rolls L, to be further crushed to pass through a riddle covered with a copper plate having holes 2 millimetres (0·08 inch) in diameter. These rolls are 38 centimetres (14·96 inches) in diameter by 33 centimetres (12·99 inches) in width, and are driven at a speed of about 50 feet at the periphery per minute. The rolls suggested in the plan of proposed dressing-floors have a diameter of 50 centimetres (19·68 inches) and a width of 34 centimetres (13·39 inches), as likely to be more efficient, for those in use at Sentein in this department did not do enough work. The surfaces of the rolls are chilled to a depth of 3 centimetres (1·18 inch), but they are not grooved. The construction is the same as that of the rolls already described, excepting the mode of keeping them pressed together. Instead of levers and a balance-box, a spring, formed of layers of thick india-rubber, was used, which could be tightened when required. It was considered that the india-rubber spring yielded too much, and that more rigidity and better work would be done by levers and a balance-box weighted to suit requirements. Precautions should be taken that crushing-rolls should be always supplied with ore-stuff, otherwise the external ring and even the levers are liable to be broken.

The chatts from the fourth and fifth jiggers are pulverized in one of Hall's grinding-mills, placed at P, Plate 7, Figs. 1. It consists of two renewable cast-iron grinding-plates with chilled faces, B B, Plate 8, Fig. 29, bolted to two permanent driving-plates C, D, within a casing of cast-iron. These grinding-plates are slightly concave and have races cast in them, representing those

cut in millstones. The upper one is 52½ centimetres (20·67 inches), and the nether one 55 centimetres (21·65 inches), in diameter. Their axes are set 3 centimetres (1·18 inch) out of centre so as to produce an eccentric motion between them when set in rotation. The nether plate is directly connected with the driving-motor by gearing, and makes about 200 revolutions per minute. The axis of the upper driving-plate, C, Fig. 29, is truncated, and projects for some distance beyond the casing of the mill. The projecting part carries a worm-wheel gearing into a screw. To produce the necessary grinding action the upper plate is driven at a much lower speed than the nether one. This may be effected either by a pinion on the driving-shaft, communicating motion to a larger pinion on the axis of the endless-screw by a driving-chain, as in Plate 8, Fig. 30; or else by a frictional brake. This brake consists of a conical gland, in three or four parts, inserted between the bearing of the axle of the endless-screw and the axle itself. A screwed collar forces the gland between the bearing and the axle which is adjustable, and the required speed of the upper plate is obtained by the friction produced. The plate can be prevented from turning, but this should be avoided, as unequal wear of the grinding face would ensue. The upper plate is kept pressed upon the nether plate by levers with movable weights which can be raised or lowered by the screw F, Fig. 29. The ore is regularly and gradually supplied to the plates through the central projection, but is not reduced to extreme fineness in one operation. Repeated grinding is resorted to, so that between each operation particles of galena and blende may be separated by dressing, of as large size as possible.

The crushed and pulverized ores are conducted by a launder to four classifiers, O_1 . . O_4 Plate 7, Fig. 1, of the same construction as those previously described, but of different depths. The first classifier, O_1, has a depth of 12 centimetres (4·72 inches); the second, O_2, of 16 centimetres (6·30 inches); the third, O_3, of 20 centimetres (7·87 inches); but the fourth, O_4, is similar to that shown by Plate 7, Figs. 5 *a*, *b*, *c*. These divide the grains of ore according to their respective sizes. The first two classifiers supply ore-stuff to two five-compartment jiggers, S_1 S_2, Plate 7, Fig. 1; the third classifier feeds a four-compartment jigger, S_3. The fourth classifier supplies "fines" and "slimes" to a round buddle U. The jiggers and buddle are of the same pattern as those previously described.

The depth of each compartment of the first jigger, from the lip at the overflow to the top of the sieve, is 60 millimetres (2·36

inches); of the compartments of the second jigger 55 millimetres (2·16 inches); of those of the third jigger 50 millimetres (1·97 inch). The plates of the first jigger have holes 3 millimetres (0·12 inch) in diameter; those of the second and third jiggers 2½ millimetres (0·10 inch). The piston of the first jigger gives about 250 pulsations per minute; that of the second about 270; and that of the third about 300 pulsations.

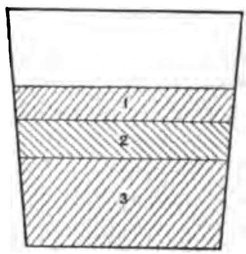
The results directly obtained from these jiggers depend on the quality of the chatts under treatment, whether they are rich or poor; but the principles upon which they are worked are the same as those of the jiggers $G_1 \ldots G_5$, Plate 7, Fig. 1. It was very difficult to completely free the galena in this department from the blende, and second-class lead ores were only obtained averaging 69 per cent. Pb. The blende contained as much as 4 per cent. Pb to 42 per cent. Zn. To obtain these results the chatts were re-crushed several times, and treated again and again. It was estimated that from 8 to 10 tons of chatts were passed through this pair of rolls and the grinding-mill per day.

7. *Dolly-work, or tossing and packing.* The different classes of fine ore having been enriched by buddling, to from 50 to 60 per cent. of lead for galena, and from 39 to 40 per cent. of zinc for blende, are further enriched by dollying or tossing.

The dolly is a tub made of oak 4½ centimetres (1·77 inch) thick, strongly bound round with iron hoops. In the tub is a fan A, Plate 8, Fig. 26. The dolly rests firmly on the flooring, but should never be packed round the bottom. Manual labour is used at Sentein to work the dollies, but mechanical means should have been adopted. In Cornwall a lighter fan is driven by overhead motion, which can be easily thrown out of gear, and the fan removed. The Author suggests a plan, as shown in Plate 8, Fig. 26, to work the dolly by mechanical means so far as the striking is concerned. D represents the main shafting upon which a bevel-wheel can be put into gear by a clutch and lever (not shown). The toothed wheel E under the dolly drives three pinions, one of which is shown at F keyed on the vertical shafting of the striker, supported by the stand O. At the top of the shafting is a cam K (and H, Figs. 27) working against a stop H, Fig. 26, fixed on the square bolt M, at the end of which is a striker L of about 8 lbs. weight. A strong spring is placed between the striker and the head of the stand, capable of giving a blow of about 30 lbs. when the striker is pulled back 4 centimetres (1·57 inch). The stop H, Fig. 26, can be adjusted by a screw so that it may give lighter blows if necessary.

The ore-stuff is treated in the following manner: Water is put into the dolly to the level of the top of the fan, and the fan is made to revolve whilst a man throws in the ore-stuff, until the ore and water nearly fill the dolly. The fan is made to revolve for a few minutes longer, and then removed from the tub as quickly as possible without stopping the rotary motion of its contents, and the strikers at once set to work. The heaviest particles subside to the bottom of the tub, the lighter ones rising to the surface.

The number of blows and their power depend upon the coarseness or fineness of the ore-stuff. The finer the ore the lighter the blows and the quicker in succession. From eighty to one hundred and fifty blows per minute are required, and the knocking is continued for forty or fifty minutes until the ore has "packed" or settled in the tub. The water is then drawn off from a plughole in the side of the dolly, and the ore examined with a vanning shovel. At the top will be found a stratum of sand and a little galena and blende, then a stratum of mixed galena and blende, and lastly galena ready for market. When blende is treated, the top stratum contains sand and blende, the middle stratum is put to pile ready for market, and a little at the bottom of the tub is treated again for the lead in it. Ore-stuff containing 60 per cent. of metallic lead, when finished in the kieve, was divisible into three layers, as shown in the annexed Fig., of which No. 1 assayed 5 per cent., No. 2, 41 per cent., and No. 3, 74 per cent. of lead. Ores of different sizes should on no account be mixed before treatment in the dolly. R, Plate 7, Fig. 1, shows the position of the dollies in the proposed floors.



The flat buddles, Plate 8, Figs. 25 *a*, *b*, are erected outside the floors and covered with a light shed. Two would do all the work of the floors. About 1½ cwt. of galena from the jiggers is put on one side of the water-supply X, Fig. 25*a*; the water is turned on, and with a hoe-shaped tool the mineral is passed little by little across the stream, which washes out slimes and small particles of blende from the galena. Blende is not submitted to this operation. The slimes are deposited in the trunk at the end of the buddle. Some lead ores, containing about 60 per cent. Pb, can be enriched to about 78 per cent. Pb by this means. The flat buddle is a simple wooden structure with an iron plate fixed at X, upon which the ores are worked.

8. *Treating slimes, &c.*—Unfortunately the automatic means of treating the ores at Sentein did not extend to the slimes. These were collected in pits, which were occasionally emptied, and the accumulated stuff was put aside for future operations. For the economical treatment of slimes they should, however, not be allowed to dry and cake. Exposure to the atmosphere for any length of time decomposes the ores, and particles that were once free adhere to others, and it is then very difficult and costly to so mix them in water as to separate the valuable mineral from the gangue. The whole of the thick water from the dressing-floors should pass over a large classifier like that shown in Plate 7, Figs. 5, *a*, *b*, *c*. The concentrated ore-stuff drawn from this classifier could be treated directly by various means, such as shaking-tables, or self-acting Cornish frames, or even buddles.

Finally, the water is conducted to triangular slime-basins (Plate 7, Figs. 12); the stream flowing over a straight-edge A at one of the angles of the first triangle, spreads out as it advances towards the opposite side, losing its velocity, and depositing the particles held in suspension, passes in a thin film over a straight-edge extending along the base of the first triangle into a parallel launder below, which carries it to the head B of the second triangle, and so on, to others, until the water is clear enough to be returned to the river.

The cost of dressing 8,235 tons of ore-stuff was at the rate of 3·20 francs (about 2*s.* 6¾*d.*) per ton, from which 879 tons of market lead ore, and 2,720 tons of market blende, were obtained. About thirty persons were employed, men being paid 2·25 to 2·75 francs per day, and lads and women 1·25 to 1·50 franc per day.

It was found that one small crusher, one large pair of rolls, a set of five four-compartment jiggers, with the necessary trommels and elevator, could be worked by an over-shot water-wheel 22 feet in diameter by 4-feet breast, supplied with 1·20 cubic metre (42·3 cubic feet) of water per minute. This is equal to 17·6 HP., but taking the effective at 70 per cent., the power utilized would be about 12·3 HP. The addition of a large stone-breaker would need about 4·6 HP. extra, say 17 HP. for one-half the department, treating crude ore, Plate 7, Figs. 1. The one-half of the department treating chatts and ragging, that is, one pair of rolls, one grinding-mill, two five-compartment jiggers, one four-compartment jigger, elevators, &c., required about 8 HP. Therefore about 50 HP., as obtained from water-power, would be needed to work the whole dressing-floors (Plate 7, Fig. 1), to treat 65 tons of crude ore per twelve hours. As already mentioned, the overflow

from the classifiers supplies the motive power for the round buddles.

The clear water was supplied to the various machines for dressing purposes through a main of 75 millimetres (2·95 inches) internal diameter, extending the entire length of the building under a head of about 6 feet pressure. India-rubber belting connected the various jiggers and buddles with the main driving shaftings.

The Paper is accompanied by numerous diagrams, from which Plates 7 and 8 and the Fig. in the text have been prepared.

(*Students' Paper No. 200.*)

"Recent Researches in Friction." [1]

By JOHN GOODMAN, Wh. Sc., Stud. Inst. C.E.

IN recent scientific researches, the investigation and study of the laws of friction must certainly be classed amongst the most important. Until lately, erroneous and vague views were entertained, mainly on account of the absence of any well-ascertained data based on scientific and practical experiments, although the great importance of the subject was fully realized. This department of applied science claims the careful attention and study of the practical engineer as well as of the theorist, from the fact alone that frictional resistance is a constant and ever-recurring source of waste work; but in order that the student may arrive at a correct conclusion, he must examine the most recent experimental results, for the whole subject has been completely revolutionized within the last few years.

Amongst the first explorers in this field of labour was one of the most original and scientific engineers of the last generation, namely, the late General Morin, who gave much time to this subject, and obtained results of a very varied nature both with dry and with lubricated surfaces on every possible constructive material. Owing, however, to the extremely low pressure and speeds with which he worked, his results are not regarded as of much value in the light of modern experiments, such as those of Professor Thurston, Mr. Beauchamp Tower, M. Inst. C.E., under the auspices of the Institution of Mechanical Engineers, and of Mr. W. Stroudley, M. Inst. C.E., who experimented in a more practical manner on the axles of railway trains and locomotives, under conditions similar to those encountered in actual practice. Engineers in America have been working in a similar direction; Mr. Woodbury on the friction of revolving disks; Mr. Wellington on the total resistance of trains, which includes the friction on the journals, tires, &c.; and last, but by no means least, there

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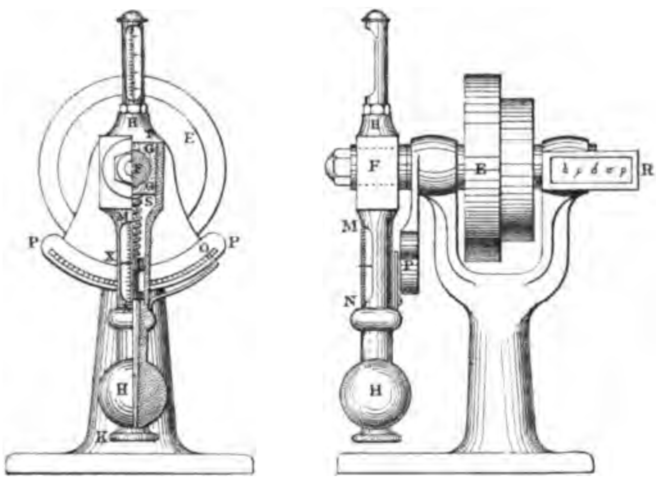
[1] This Paper was read at a meeting of the Students on the 20th of November, 1885.

are the well-known experiments of Messrs. Galton and Westinghouse, on the brake-friction of railway vehicles, the most important of which were carried out on the Brighton Railway with the co-operation of Mr. Stroudley.

The Author's object in contributing this Paper is to compare these various results, and to examine the phenomena which have been obtained from a theoretical point of view. The laws of dry friction must be considered from an entirely different standpoint from those of the friction of well-lubricated surfaces, although in some cases it is a very difficult, if not an impossible

Figs. 1.

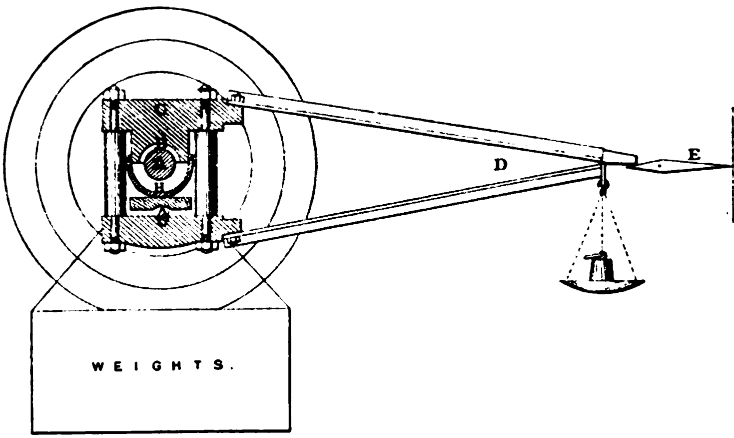


task to define accurately where the one condition begins and the other ends; for example, some revolving journals, although originally fully lubricated, behave as dry surfaces when the supply of lubricant diminishes. The apparatus used by the most recent experimenters is shown in the illustrations. Figs. 1 represent Professor Thurston's machine. F, the journal on which it is desired to measure the frictional-resistance, is driven by a belt running on the pulley E. The brass, G, is fitted into the upper part of the pendulum HH; the desired pressure on the brasses is applied by turning the hand-screw K, which compresses the spiral spring S; PP is a graduated arc transversed by the pointer O, which is attached to the pendulum. The quotient of this reading by the total pressure indicated by the pointer X gives the co-

efficient of friction. On the top of the brass is a thermometer to register the heat of the journal; R is a revolution-indicator; the lubricant is supplied through a small hole at T. When the journal revolves the friction on the brass causes the pendulum to be deflected.

Mr. Tower's machine, Fig. 2, resembles the last in some points, but for the spiral spring a dead weight is substituted to give the desired load on the brass. A is the revolving journal, B is the brass bearing, carrying the frame C, on the lower part of which is a knife-edge C^1, situated immediately under the centre of the journal, from which is suspended the weights; D is a long light

FIG. 2.

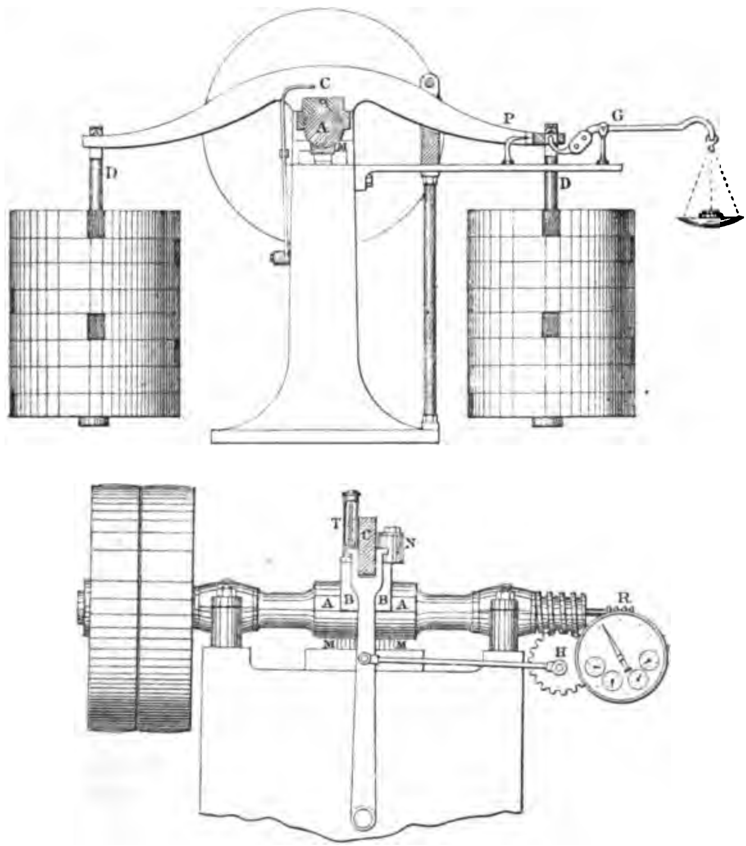


angle-iron frame with a scale-pan suspended from its extremity, into which are placed weights to counterbalance the turning moment of the friction. E is a pointer and graduated scale to indicate when the whole frame is in its normal position. H is an oil-bath into which the bottom of the journal dips, and so keeps up a thoroughly good supply of lubricant.

In Mr. Stroudley's machine, Figs. 3, the essential difference from the last-mentioned is the arrangement for applying the load to the brass. A is the revolving journal, several sizes of which are used corresponding to the various axles of a train. B is the brass bearing fitted into the weight-beam C, at each end of which is a knife-edge carrying a weight-suspending link D. G is a small scale-beam and pan into which weights are placed to counterbalance the moment of the friction. H is a small eccentric

and wheel, driven by a worm on the main shaft, which keeps the bearing continually moving to and fro to represent the side-play always given on locomotive axles. M is an oil-pad which keeps the journal constantly lubricated. N is a siphon lubricator. R is

Figs. 3.



a revolution indicator. T is a thermometer to register the heat of the journal. P indicates when the beam is in its normal position.

The frictional resistance is calculated thus (Fig. 4):—

Let x = radius of the journal in inches.
W = the total load on the brass in ozs.

Then with the dimensions as shown, a weight in the scale-pan acts at a leverage of $72 \div x$ on the surface of the journal; so that 1 lb. in the pan is equivalent to $\frac{72}{x}$ lbs. frictional resistance on the brass. Then—

$\frac{72}{W x}$ = the coefficient of friction corresponding to each oz. in the scale-pan.

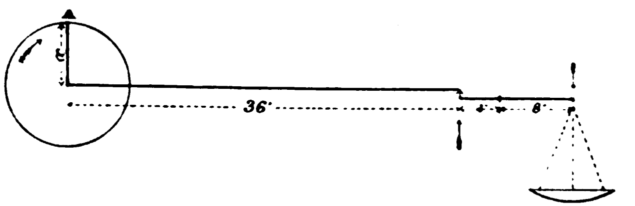
The total frictional resistance on the brass =

$$\frac{72 \text{ (weight in scale-pan)}}{x}.$$

The frictional resistance per square inch =

$$\frac{\text{Total frictional resistance}}{\text{nominal area of brass}}.$$

FIG. 4.



The nominal area = the length of the journal × the chord of the arc of the brass in contact. The HP. required to overcome this resistance is calculated by formulas given further on. By comparing and examining the observed results obtained from these machines, the following laws become apparent.

WELL-LUBRICATED SURFACES. (Oil-bath.)

1. The coefficient of friction with the surfaces efficiently lubricated is from $\frac{1}{6}$ to $\frac{1}{10}$ that for dry or scantily lubricated surfaces.

2. The coefficient of friction for moderate pressures and speeds varies approximately inversely as the normal pressure; the frictional resistance varies as the area in contact, the normal pressure remaining constant.

3. At very low journal-speeds, the coefficient of friction is abnormally high; but as the speed of sliding increases from about 10 to 100 feet per minute, the friction diminishes, and again rises when that speed is exceeded, varying approximately as the square root of the speed.

4. The coefficient of friction varies approximately inversely as the temperature, within certain limits, namely, just before abrasion takes place.

The evidence upon which these laws are based is taken from various modern experiments. That relating to Law 1 is derived from the "First Report on Friction Experiments," by Mr. Beauchamp Tower.

TABLE X.[1]

Method of Lubrication.	Coefficient of Friction.	Comparative Friction.
Oil bath	0·00139	1·00
Siphon lubricator	0·0098	7·06
Pad under journal	0·0090	6·48

With a load of 293 lbs. per square inch, and a journal speed of 314 feet per minute, Mr. Tower found the coefficient of friction to be 0·0016 with an oil bath, 0·0097 with a pad, which is six times the amount of friction with the latter. Under the same conditions, Mr. Stroudley obtained a coefficient of 0·00961, which is a very close approximation.

The very low coefficients obtained by Mr. Tower will be accounted for by Law 2, as he found that the frictional resistance per square inch under varying loads is nearly constant.

TABLE I.[2]

Load in lbs. per square inch	520	468	415	363	310	258	205	153	100
Frictional resistance per square inch . . .	0·416	0·514	0·498	0·472	0·464	0·438	0·43	0·458	0·45

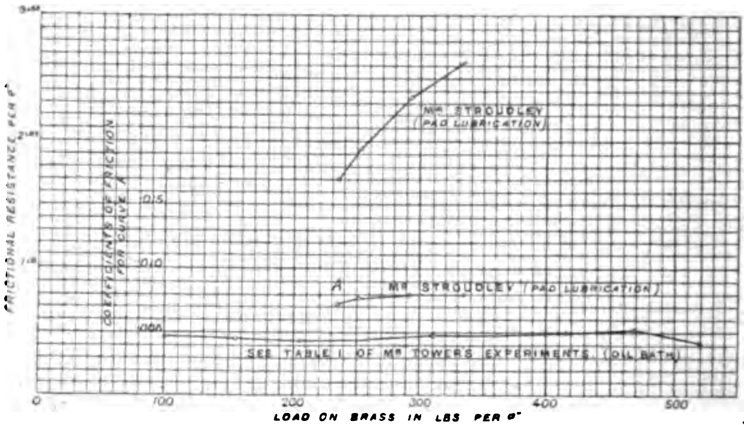
It should be noted here that the frictional resistance per square inch is the product of the coefficient of friction into the load per square inch on horizontal sections of the brass. Hence, if this product be a constant, the one factor must vary inversely as the other, or a high load will give a low coefficient, and *vice versâ*.

[1] Institution of Mechanical Engineers. Proceedings, 1883, p. 651.

[2] *Ibid.*, p. 643.

For ordinary lubrication, the coefficient is more constant under varying loads; the frictional resistance then varies directly as the load, as shown by Mr. Tower in Table VIII. of his report,[1] and also

FIG. 5.



from the following results obtained by Mr. Stroudley with a pad of standard Globe oil, as used for carriage-axles on the Brighton Railway.

Load per square inch on Brass.	Coefficient of Friction.	Frictional Resistance per square inch.
Lbs.		Lbs.
333	0·00792	2·639
293	0·00800	2·34
251	0·00770	1·93
237	0·00720	1·70

With respect to Law 3, Mr. A. M. Wellington, of the American Society of Civil Engineers, made a large number of experiments, on journals revolving at very low velocities, and found that the friction was then very great, and nearly constant under varying conditions of the lubrication, load, and temperature. But as the

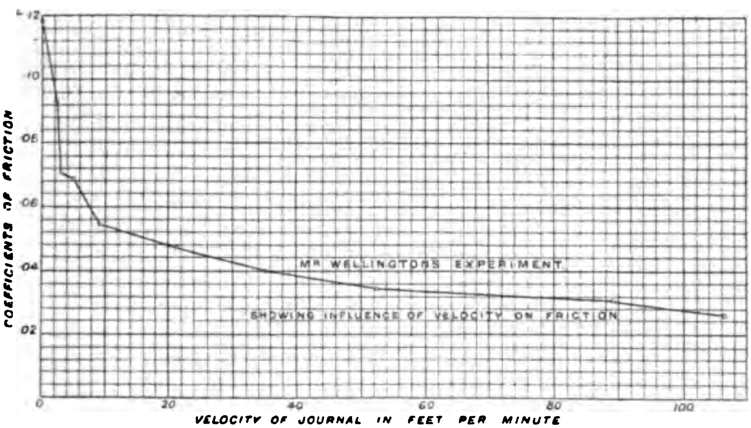
[1] Institution of Mechanical Engineers. Proceedings, 1883, p. 650.

speed increased the friction fell slowly and regularly, and again returned to the original amount when the velocity was reduced to the same rate.[1]

The following Table shows this clearly (Fig. 6):—

Feet per minute .	0 +	2·16	3·33	4·86	8·82
Coefficient of friction	0·118	0·094	0·0705	0·0685	0·055
Feet per minute .	21·42	35·37	53·01	89·28	106·02
Coefficient of friction	0·047	0·040	0·035	0·030	0·0255

FIG. 6.



It was also found by Professor Kimball, that when the journal velocity was increased from 6 to 110 feet per minute, the friction was reduced 70 per cent.; in another case, the friction was reduced 67 per cent. when the velocity was increased from 1 to 100 feet per minute; but after that point has been reached the coefficient of friction varies approximately with the square root of the velocity, this law was pointed out by the late Mr. W. R. Browne, M. Inst. C.E.[2] The observations are by Mr. Tower.

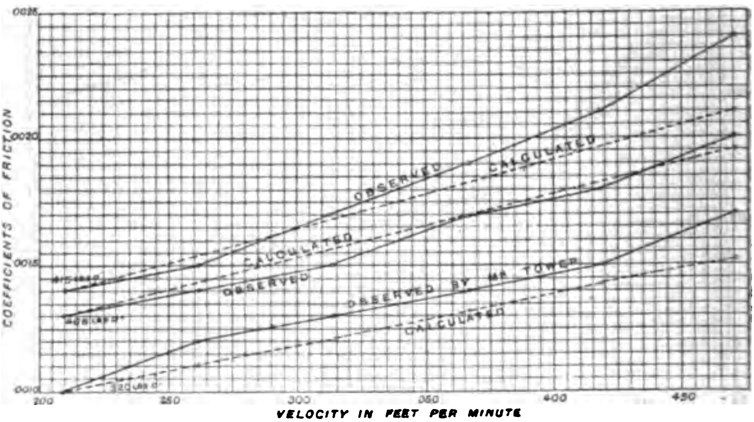
[1] Transactions of the American Society of Civil Engineers, 1884, vol. xiii., p. 409 *et seq.*

[2] The *Engineer*, 1884, vol. lviii., pp. 57, 58.

COEFFICIENTS OF FRICTION, FOR SPEEDS AS BELOW (FIG. 7).

Feet per minute.	209.	262.	314.	366.	419.	471.	Nominal Load per square inch.
							Lbs.
Observed . .	0·0010	0·0012	0·0013	0·0014	0·0015	0·0017	520
Calculated .	0·0010	0·00118	0·00123	0·00132	0·00141	0·0015	
Observed . .	0·0013	0·0014	0·0015	0·0017	0·0018	0·002	468
Calculated .	0·0013	0·00145	0·00159	0·00172	0·00184	0·00195	
Observed . .	0·0014	0·0015	0·0017	0·0019	0·0021	0·0024	415
Calculated .	0·0014	0·00157	0·00172	0·00185	0·00198	0·0021	

FIG. 7.

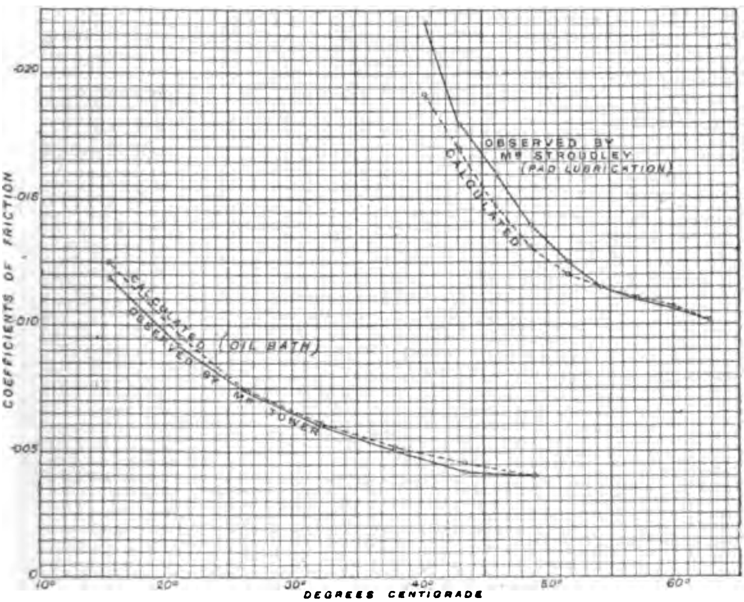


The variation of friction with temperature is approximately in the inverse ratio, Law 4. Take, for example, Mr. Tower's results, at 262 feet per minute, as shown in the following Table:—

Temperature, Centigrade	43·4°	37·8°	32·2°	26·7°	21·1°	15·6
Observed	0·0044	0·0051	0·006	0·0073	0·0092	0·0119
Calculated	0·00451	0·00518	0·00608	0·00733	0·00964	0·01252

This law does not hold good for pad or siphon lubrication, as then the coefficient of friction diminishes more rapidly for given increments of temperature but on a gradually decreasing scale until the normal temperature has been reached; this normal temperature increases directly as the load per square inch, as shown in the

FIG. 8.



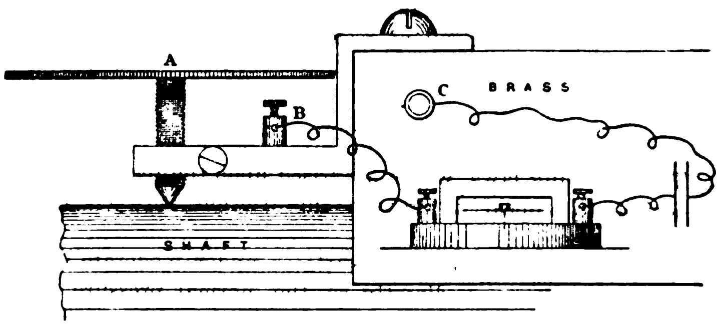
following Table taken from Mr. Stroudley's experiments with a pad of rape oil (Fig. 8):—

	°	°	°	°	°	°	°	°	°
Temperature, Fahrenheit	105	110	115	120	125	130	135	140	145
Temperature, Centigrade	40·56	43·34	46·1	48·9	51·7	54·4	57·2	60	62·78
Coefficient .	0·022	0·0180	0·0160	0·0140	0·0125	0·0115	0·0110	0·0106	0·0102
Decrease of coefficient .	..	0·0040	0·0020	0·0020	0·0015	0·0010	0·0005	0·0004	0·0002

From the above considerations it may be fairly assumed that

the friction of lubricated surfaces is very different in nature from the friction of dry surfaces. One essential point is that in well-lubricated surfaces the brass and journal are not in contact, but are separated by films of oil, the one adhering to the brass, the other to the journal. The resistance, therefore, is due to the shearing action between the two films. There is no doubt whatever but what this film actually exists, for the brass with its load is bodily raised as soon as the journal begins to revolve. The Author has not only proved this for himself, but has also measured accurately the thickness of the film with a piece of apparatus of his own design. The experiment was carried out on Mr. Stroudley's machine (Fig. 9), where A is a micrometer screw capable of measuring to 0·0001 inch, carried by a small bracket fastened to the brass, but electrically insulated from it by paraffined paper.

FIG. 9.



B and C are terminals for attaching insulated wires to a weak voltaic cell and galvanometer. When the micrometer touches the shaft the galvanometer is deflected; this is set so that there is contact when the shaft is at rest, but immediately it is put in motion the brass with the micrometer is raised and the circuit is broken; the screw is again set to just touch the shaft, when the micrometer indicates the height to which the brass has been raised. The amount was found to vary with the efficiency of the lubrication. With a pad-lubricator it was raised to 0·0018 inch on first starting, and as the films became better developed the friction decreased and the brass was ultimately raised 0·0029 inch. It was found by Mr. Tower that there was an immense pressure of oil between the brass and the journal, equivalent at a certain point to more than double the nominal load per square inch.

In making a similar experiment with Mr. Stroudley's machine,

the Author found that ordinary lubrication with a pad failed to give any pressure on the gauge, but if the pad was dipped in oil and applied in a dripping condition, the pressure immediately rose, and gradually sank as the oil-supply diminished; thus the pressure-gauge became a good indicator of the efficiency of the lubrication. In the same experiment it was found that the coefficient of friction was about 25 per cent. lower when the oil-hole on the top of the brass was closed with a screwed plug, thus indicating that the oil escaped at the apex of the bearing, and so prevented a cushion or film of oil being effectually formed.

With well-lubricated surfaces the amount of wear is extremely small, even at high surface velocities; for instance, on the Brighton railway there are many cast-iron eccentric straps working on cast-iron sheaves, which have been running constantly for twelve or thirteen years without requiring the slack to be taken up; their surface velocity is about 900 feet per minute, representing in thirteen years a distance of at least 100,000 miles passed over by the surfaces. This excellent result is due to the thoroughly good system of lubrication adopted.

Dry Surfaces.

The following laws, which are based upon the results of modern experiments, appear to govern the friction between dry surfaces:—

1. The friction between dry surfaces under moderate loads and low velocities, varies directly as the normal pressure between them.
2. The normal pressure remaining unchanged, the friction is independent of the area in contact.
3. It is always greater on the reversal of direction of sliding.
4. It sensibly diminishes with a rise of the temperature.

1. In the "Galton-Westinghouse" experiments it was found that with velocities below 100 feet per minute, and with low pressures, the frictional resistance varied directly as the normal pressure; but when a velocity of 100 feet per minute was exceeded, the coefficient of friction greatly diminished; from the same experiments Professor Kennedy found that the coefficient of friction for high pressures was sensibly less than for low.

2. This law is best demonstrated by arranging an inclined plane of suitable material, and placing on it several bodies of the same weight and similar material, but with different areas in contact;

when a sufficient inclination is given to the plane, they will all start sliding together; thus the area in contact does not affect the coefficient of friction.

3. This law can be demonstrated by attaching a string to a sliding body on a horizontal plane; the string passes over a grooved pulley to a scale-pan in which are placed weights just sufficient to made the body slide; but if the body be turned round so that its direction of sliding is reversed, the original weights will be insufficient to cause sliding, showing that the friction is greater. This law is also true for lubricated surfaces.

4. In the experiments on brake-blocks, it was found that they became considerably heated after successive applications, and at the same time the coefficient of friction sensibly diminished.

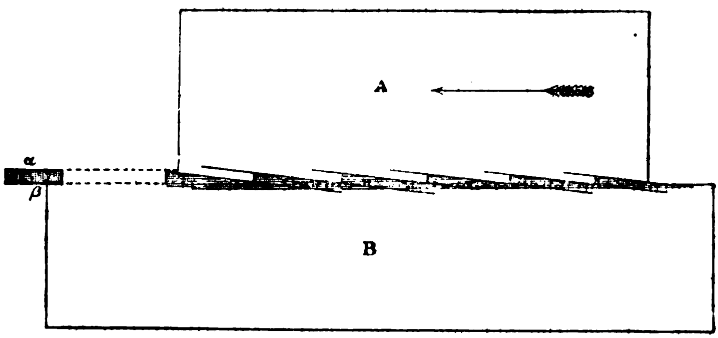
Possibly this may be the reason why the friction diminishes with increased pressures, for the heat generated by friction varies as the normal pressure.

The theoretical consideration of "dry friction" is of a much more complex nature than that of lubricated surfaces, but if it be assumed as a basis that all the surfaces of solid bodies resemble in structure the surface or pile of velvet, many, if not all the difficulties will be easily overcome. However smooth the surfaces may appear, a pile will still be left; for as the original surface is worn away, particles of metal are torn from the main body, each of which will leave its own jagged hole, and constitute a fresh pile as the old one is removed. An illustration of this is seen when a piece of wood is filed transversely to the grain; as long as the filing is continued a rough surface is left. The pile will necessarily partake of all the physical properties of the metal, its tenacity, elasticity, coarseness of grain, &c. The latter property will determine the degree of fineness, or "pitch of the pile," which is simply the relative number of fibres or piles per unit of area.

When two such surfaces are pressed together, the pile will become partially flattened, and will not leave a perfectly smooth surface, but one consisting of minute indentations and projections, the latter on one surface fitting into the former on the other. Hence, before any sliding motion can take place, the projections on the one must mount up and pass over those on the other, which constitute a series of minute inclined planes. But before this motion can take place, a force must be applied to the sliding body, one component of which acts in opposition to the normal pressure; the force required to make a body slide up these inclined planes is the resistance of friction, hence the greater the normal pressure, the greater is the resistance to sliding. If the normal pressure be

too great, abrasion takes place, and the resistance is greatly increased, because the force now required to produce sliding must be sufficient to tear the pile or fibres from the metal. Fig. 10 illustrates how the pile causes the frictional resistance, the pile being highly exaggerated to show the effect more clearly. A and B are two masses of metal, of which A slides over B; now it is evident that before any sliding can take place, A must be vertically raised through the distance $\alpha\,\beta$; then while sliding is taking place, A is being constantly raised and allowed to fall through $\alpha\,\beta$. The force required to maintain this motion is the frictional resistance; the blow given at each fall is converted into heat, and hence the heat caused by friction is simply due to the impact of the bodies.

FIG. 10.



The total amount of work done against frictional resistance may be expressed thus—

Let n = the number of projections, piles, or fibres per lineal inch.

Let the space $\alpha\,\beta$ (Fig. 10) = $\cdot\,\theta$ inch.

Let the normal pressure = ϕ lbs.; then the work done in making A slide through 1 inch is—

$$W = \frac{n \times \theta \times \phi}{12} \text{ foot-lbs. of work.}$$

In Fig. 11, let xy represent an inclined plane, with a body Z just beginning to slide by its own weight, then $\tan\phi$ will be the coefficient of friction; now it is evident that the pile must be flattened by the sliding body, so that the side of each fibre is level, or slightly lower at the tips, hence it follows that the coefficient of friction is the tangent of the angle which the side of each loaded fibre makes with the surface of the plane on flat surfaces.

It will now be seen why the friction is independent of the area in contact, the normal pressure remaining unchanged, as the resistance is only dependent upon the height $\alpha\,\beta$. When the direction of sliding is reversed, the pile, which is already flattened in the original direction, must describe the arc of a circle before it can be flattened in the reverse way (Fig. 12), and then the vertical distance $\alpha\,\beta$ is increased to $m\,n$, which will account for Law No. 3.

If the temperature of the surfaces is high, the pile is more pliable, and consequently becomes more flattened, which reduces the height $\alpha\,\beta$, with a corresponding diminution of friction.

When the velocity of sliding is very small, the projections on one surface sink completely into the indentation on the other;

FIG. 11.

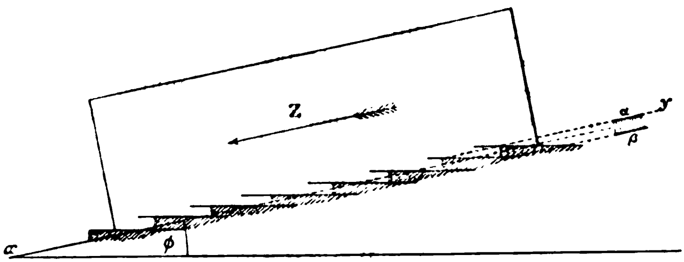
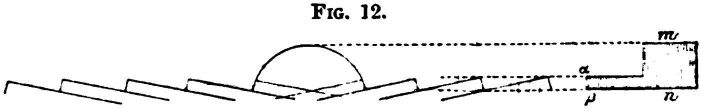


FIG. 12.



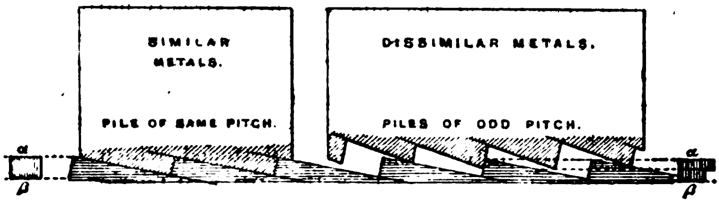
but when the velocity is increased, the tips of the fibres only come in contact, as there is not sufficient time for the one to sink its full depth into the other, which again reduces the vertical height $\alpha\,\beta$; but in the case of high velocities of revolving bodies, another force comes into operation; so-called centrifugal force acts on the pile and stiffens it, as it tends to fly from the centre, for the same reason that revolving brushes are always stiffer at high velocities than at low, this stiffening increases the friction, as each pile has to be flattened before passing under the bearing.

The coefficient of friction is always higher with similar, than with dissimilar metals; the reason of this may be seen from Fig. 13; in the second case, the vertical height $\alpha\,\beta$ is considerably less than in the first.

The problem, to find the work absorbed by friction, is one

which often occurs in practice; it may therefore be useful to consider the method.

FIG. 13.



Let P = normal pressure in lbs.;
u = coefficient of friction, namely, the ratio of the resistance to the load;
s = space in feet through which sliding takes place;
t = time in minutes during „ „ „ „
n = number of revolutions per minute;
v = velocity of sliding, in feet per minute;
a = number of square inches of surface in contact;
d = diameter of journal in inches;
W = work absorbed in foot-lbs.

Then for flat surfaces $W = P \times u \times s$.

$$HP. = \frac{P \times u \times v}{33{,}000}.$$

Cylindrical journals per revolution— $W = \frac{P \times u \times 3 \cdot 1416\, d}{12}$.

$$HP. = \frac{P \times u \times 3 \cdot 1416 \times d \times n}{12 \times 33{,}000}.$$

The frictional resistance of a sliding body is expressed thus:—

$$P \times u.$$

Frictional resistance per square inch:—

$$\frac{P \times u}{a}.$$

To calculate the HP. absorbed by friction in a train—

Let N = the number of square inches (nominal) of bearing-surface in the whole train;
F R = average or mean frictional resistance per square inch on all the journals;
J S = average or mean velocity in feet per minute of all the journals.

$$\text{Then HP.} = \frac{N \times FR \times JS}{33{,}000}.$$

The pull on the draw-bar due to journal friction per ton weight of train—

Pull in lbs. $= \dfrac{u \times 2{,}240}{r}$, where r is the ratio of the radius of wheel to the radius of journal.

In calculating the load on the journals of railway-axles, it must be borne in mind that the dead-weight of the vehicle on the brass is only a part of the total load; the other factor of total load is the rolling-resistance of the wheels in the direction opposite to that in which the train is travelling; the amount of this second factor is at present unknown, and can only be ascertained by a special experiment; but however great this pressure may be, the brass does not wear in that direction, but always on the forward side of the brass. The same observation has been made in marine-engine journals, which always wear in exactly the reverse way to what they might be expected. Mr. Stroudley thinks this peculiarity is due to a film of lubricant being drawn in from the under-side of the journal to the aft part of the brass, which effectually lubricates and prevents wear on that side; and that when the lubricant reaches the forward side of the brass, it is so attenuated down to a wedge-shape that there is insufficient lubrication, and greater wear consequently follows.

The Author was engaged by Mr. W. Stroudley, M. Inst. C.E., in carrying out these experiments on friction, and is greatly indebted to him for permission to place the results arrived at before the Students of the Institution.

The communication is illustrated by several diagrams, from which the Figs. in the text have been engraved.

OBITUARY.

FREDERICK MORRIS AVERN was educated in the Engineering Department of King's College, London; he subsequently served a pupilage of two years to Mr. C. P. B. Shelley, M. Inst. C.E., and was for some months employed on the works of the Charing Cross Railway Bridge, under Mr. Joseph Phillips, Assoc. Inst. C.E. In June 1863, at the notably early age of eighteen, he passed the competitive examination for the Indian Public Works Department, and entered that service as a Stanley engineer. He rose rapidly in the department, thus fulfilling his early promise. He was at first employed in a subordinate position on the Nuddeah River Improvements and other fluvial works, but three years after entering he was appointed to the charge of the Calcutta Port and Hooghly Improvement Works, with the rank of Executive Engineer. In August 1871 he took charge of the Sutlej Bridge Division of the Indus Valley (State) Railway. In September 1872 he was transferred to the Punjab Northern State Railway, in charge of various divisions of surveys and construction, but his most important employment was the superintendence of the erection of the greater part of the superstructure of the Jhelum bridge, of which he presented an account to the Institution.[1] This remarkable structure is nearly 1 mile long (actually 4,867 feet between the abutments), and consists of fifty spans of 97 feet 6 inches, on well-foundations. It crosses the Jhelum—the ancient Hydaspes—at a point where the river is encumbered by a bed of boulders, and by sandbanks, and is altogether a great work of engineering. After sixteen years' service in India, Mr. Avern found his health begin to suffer, and he resigned his appointment. He experienced great difficulty in getting his resignation accepted, such was the value put upon his services, but he eventually left the country in order to reside in Australia. In 1881 he again sought professional employment, and was appointed District Engineer in charge of the Great Western Railway of New South Wales. His untiring zeal and energy in this position procured for him, three years later, the post of Deputy Engineer for all the existing lines of the colony. In this capacity he rendered most important service in re-organizing the department, a class of work

[1] Minutes of Proceedings Inst. C.E. vol. liv. p. 94.

for which he had unusual talent. It is agreed, by all acquainted with the facts, that in this difficult and arduous task Mr. Avern's services were simply invaluable. He possessed the rare faculty of being strict and exacting without giving offence, or becoming in the least unpopular. But, as frequently happens where so much labour is compressed into so short a span, Mr. Avern's life-work was finished at an age when that of most men has scarcely reached its meridian. He died on the 14th of March, 1886, when but little over forty. He was elected an Associate on the 3rd of May, 1870, and transferred to Member on the 28th of November, 1876, both dates signifying nearly the earliest age at which he was qualified for the distinction.

GEORGE WILLOUGHBY HEMANS[1] bore a name that must ever find a home in the hearts of those who love to see exquisite fancy, beautiful feeling, and pure thought clothed in the language of poesy. He was the son of the poetess Felicia Hemans, his father being an officer in the 4th (King's Own) Regiment, who, having served with distinction in the Peninsular War and the Walcheren Expedition, had settled in the romantic district of St. Asaph, in North Wales. Here the subject of this memoir was born, on the 27th of August, 1814. In 1818 his father, Captain Alfred Hemans, whose health had been long impaired, was induced to try the effects of a southern climate, and became domiciled at Rome, the education of his children being arranged for by their mother, who continued to reside at St. Asaph. Notwithstanding the unceasing exercise of her mental gifts, Mrs. Hemans devoted many hours each day to the labour, so dear to a woman of elevated mind, of instructing her children. It was a childish question of George Hemans, or one of his brothers, which gave birth to those most favourite and oft-quoted lines, "The Better Land." On leaving his mother's care, young Hemans, after passing some short time with his father in Italy, entered the Military College of Sarèze, in France, where he passed three years. During his sojourn at this school he exhibited all the promise of the distinction he afterwards attained, bearing away every prize, both in foreign languages, science, and drawing, and leaving the establishment with no less than six medals.

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[1] Much of the information contained in the first part of this notice is derived from the *Illustrated London News* of August 10, 1851.

Mr. Hemans was next placed under the guardianship and care of his uncle, Colonel Browne, C.B., an excellent and popular magistrate of Dublin, who placed him, after filling some appointment under the Ordnance Survey with much credit, as a pupil under Sir John Macneill, M. Inst. C.E., then practising in London. In this position he was employed on several Irish and Scotch lines of railway, and on the completion of his time of pupilage was given charge, as Resident Engineer, of the Dublin end of the railway to Drogheda, the works of which were entirely confided to him by Sir John Macneill. The first two iron lattice bridges built in this country were on this line, and were constructed under Mr. Hemans's superintendence. One was a foot-bridge, of considerable span, over a deep cutting; the other a bridge of 140-feet span, carrying the railway over the Royal Canal at Dublin. After the opening of the Dublin and Drogheda line he was immediately placed in charge of a more extended division of the railway then commencing between Dublin and Cork (Great Southern and Western), and was ultimately appointed by Sir John Macneill District Engineer over 50 miles of those works.

At this juncture, however, the directors of the Midland Great Western Railway of Ireland, having obtained an Act of Parliament enabling them to construct their line to Mullingar and Longford, applied to Mr. Hemans, in August 1845, to take charge of their works as Chief Engineer. This offer he accepted, and was immediately engaged in preparing plans for the construction of their line, and for its branches and proposed extensions.

During the great depression that all railways laboured under, subsequent to the mania of 1846, but slow progress was made with the works to Mullingar; but on the 28th of June, 1847, the first portion, to Enfield, 26½ miles, was opened to the public. In the meantime, by the issue of a severe Parliamentary contest, the company had been put in possession of the line to Athlone, and in 1847 these powers were further extended to Galway. In the same year a further portion of the line to Mullingar was opened, on the 6th of December, to the public. It was not until the 2nd of October, 1848, considerable financial difficulties having much retarded the works, that Mr. Hemans could enable the directors to open their line to the public the whole way to Mullingar, and there for a considerable period all further progress was stopped.

In the following May, the extreme distress in the west of Ireland having induced the Government to consider the advantages of giving employment, by the extension of the rail to Galway, a loan was advanced to the company of half a million, to be spent on the line

between Athlone and Galway, the company themselves guaranteeing to find the means of construction from Mullingar to Athlone. A further condition, which then appeared rather startling, was annexed, which was that the whole line from Mullingar to Galway, 77 miles, must be completed by the end of December, 1851.

As the works could not be commenced until land was obtained, in the beginning of 1850, this was considered a difficult task, and was not undertaken without hesitation. Two great rivers, the Shannon and the Tuck, and an arm of the sea, were to be bridged over, and some deep bogs to be crossed, besides tolerably heavy earthworks were necessary in the county Westmeath. In the latter end of the year, the directors, at Mr. Hemans' strong recommendation, secured the services of Mr. Dargan, the eminent contractor, and early in 1850 the works were actually commenced by him, with a large staff of plant and assistants. From this time, Mr. Hemans devoted all his energies to the arrangements necessary for the completion of the line in due time. Designs were prepared for the numerous bridges, stations, &c., and for the viaducts over the Shannon, river Tuck, and the estuary of Lough Athalia. All these works were put in active operation during the summer of 1850; and the result was, that, on the 1st of August, 1851, five months before the stipulated time, and at a cost, it has been stated, considerably under the estimate, the whole line from Mullingar to Galway was opened to the public.

On the completion of the line Mr. Hemans was entertained by the directors of the company at a public banquet, when a large handsome claret-jug and salver were presented to him, bearing the following inscription:—"Presented by the Chairman and Directors of the Midland Great Western Railway to George Willoughby Hemans, Esq., C.E., in testimony of their just appreciation of the talents, energy, and judgment displayed by him in conducting the engineering works of the company to a speedy and most efficient completion MDCCCLI."

During the construction of the Midland Great Western, Mr. Hemans was connected with the engineering of several other lines in Ireland, *e.g.*, the Portadown, Dungannon and Omagh Junction; the Newry and Warrenpoint, the Newry and Armagh, the Enniskillen and Bundoran, the Athenry and Tuam, and the Athenry and Ennis Junction, the Waterford and Limerick, the Limerick and Kilkenny, and the Kilkenny Junction railways. Many of these lines were constructed under extreme difficulties for want of capital, and had it not been for Mr. Hemans's extraordinary energy and perseverance they would probably never have got beyond the

initial stage. As it was he constructed more railways in Ireland than any engineer of his time.

In 1854 Mr. Hemans came to reside in London, and speedily attained a high reputation as a parliamentary engineer. He constructed several railways in England and Wales, namely, the Vale of Clywd, the East Grinstead and Groombridge and Tunbridge Wells, and the Tewkesbury and Malvern lines. In 1865 Mr. Hemans, jointly with Mr. Bateman (Past President Inst. C.E.), deposited plans for the great scheme for the utilization of the sewage of London proposed by the "Metropolitan Sewage and Essex Reclamation Company." These works were actually commenced, but consequent upon the monetary panic of 1866, and the severe depression that ensued, they were abandoned. This proposed undertaking caused much interest when before Parliament, and was the first occasion of the Prince of Wales voting in the House of Lords, when His Royal Highness supported the second and third readings of the Bill.

In 1870 Mr. Hemans was appointed Engineer-in-Chief for the Government of the Province of Canterbury, New Zealand, and subsequently to the Government of New Zealand. Afterwards Mr. G. B. Bruce (V.P. Inst. C.E.) was appointed joint engineer with him, for the New Zealand Government.

In September 1872, while staying at Ben Rhydding, Mr. Hemans was seized with a terrible attack of paralysis.

He never recovered from this attack, nor even ever spoke again, and died on the 29th of December 1885, the last thirteen years of his life being passed in retirement in the bosom of his family. For a man of his activity of mind and body a sadder fate than this "death in life" could scarcely be imagined, but he bore his trouble with the utmost fortitude and even cheerfulness.

The form of paralysis was that by which the nerves of the brain were so affected as to deprive him of the power of speech and writing, but otherwise leaving the brain active and clear. He was able to take interest in politics, delighted in being read to, played an excellent game of whist and backgammon. Strange to say, he would copy a letter when written for him, or an etching, but he had no powers left of composition. He could not even write "yes" or "no" without assistance. Owing to the kindness of Mr. Bruce the New Zealand business was carried on most satisfactorily under their joint names.

Mr. Hemans's connection with the Institution was a highly honourable and advantageous one on both sides. At the time of his death he was within eighteen months of completing half a

century of membership, having been elected an Associate on the 2nd of May, 1837. On the 9th of January following he was transferred to Graduate, and on the 18th of May, 1845, he became a full Member. He was a most regular attendant of the meetings, frequently taking part in the discussions, and being the Author of four Papers printed in the Minutes of Proceedings, namely:—"On the Brick Beam at Nine Elms," i. (1838), 16; "Description of a Wrought-iron Lattice Bridge lately erected on the line of the Dublin and Drogheda Railway," iii. 63; "Description of the Rails, Sleepers, and Fastenings on the Dublin and Drogheda Railway," v. 233; "On the Railway System in Ireland, the Government aid afforded, and the Nature and Results of County Guarantees," xviii. 24. For the second of these communications he received a Walker Premium. His Paper on the railway system of Ireland would also have been rewarded, but for the fact of his being himself a Member of Council. In such cases it is not customary to notice Papers otherwise than by a vote of thanks.

He was elected a Member of Council in 1856. When his lamentable seizure occurred he was a Vice-President, a position which, in the ordinary course, would have in due time secured his nomination for the Presidency. He was annually re-elected until 1875, when, being the senior Vice-President, his name was, at his own request, withdrawn from nomination to the Presidency. On receiving this intimation the Council unanimously recorded their sense of the services of Mr. Hemans in the following terms.

"Resolved—That the Council hear, with the deepest possible regret, of the continued indisposition of their esteemed colleague, Mr. Hemans.

"That, having regard to the marked attention Mr. Hemans invariably showed, and the deep interest he uniformly took in all the details of the administration of the Society, the Council had looked forward with satisfaction to the period now approaching, when Mr. Hemans might have been elected President, the duties of which office, they feel assured, would have been discharged with honour and credit to himself, and with signal advantage to the Institution.

"That, in receiving his resignation, the Council desire to record how deeply they deplore the temporary loss of Mr. Hemans's distinguished services; and how earnestly they hope that at no distant date he may be restored to health, and be enabled to assume the highest office the profession has the power to bestow."

In person Mr. Hemans was slightly below the middle height, possessed of a well-built dapper form, betokening great activity, and with a handsome winning face, and most pleasant manners. He was fond of athletic exercise, and was a fearless rider, in winter mostly devoting his Saturdays to hunting, even after he came to London, and he took almost daily exercise in the park. As might be expected from his descent, Mr. Hemans was a man of the highest moral character professionally and socially; indeed his sense of honour was almost too keen for the present day. He was an open-hearted, generous and faithful friend, a favourite with all his fellow-pupils in early days, and afterwards with all who worked with him or under him, and it will ever be matter for regret that his name was not destined to be included among the list of Presidents of the Institution.

JOSEPH LEECE, eldest son of Mr. John Leece, was born at Edgley, Stockport, Cheshire, on the 8th of September, 1838. About 1840 the family removed to Manchester, where Joseph received his education, attending first a school conducted by Mr. James Howell, a friend of his father, then, for a time, the Manchester Commercial Schools, and occasionally the evening classes held at the Manchester Mechanics' Institution in that city.

At the age of fourteen he was sent to work at the engineering establishment of Mr. (now Sir) Joseph Whitworth, beginning on the lowest rung of the ladder, as lodge-boy, and rising step by step through the different departments, drawing-offices, tool-shops, &c., till in course of time he became foreman of shops. These, by his organizing skill, he greatly improved, particularly the screwing-tackle and standard-gauge shops. Everything connected with these branches has a world-wide reputation for system and accuracy. When Mr. Whitworth added to his other manufactures that of guns and rifles, Mr. Leece applied himself zealously to this branch of the business, and occupied himself with scientific experiments in connection therewith, the results of which have proved that they were ably carried out.

In 1863–4 Mr. Leece conducted the more important heavy gun trials of Whitworth *versus* Armstrong, and the experiments on the Southport range; in both cases achieving remarkable results. In small-arm practice, too, he distinguished himself, and was mainly instrumental in introducing the weapons of his employer's manufacture to the notice of influential volunteer officers in the

early days of the movement. He attended many important shooting meetings in a business capacity, and had the honour, at the opening of the first Wimbledon meeting, July 2nd, 1860, of sighting the rifle for the Queen. Owing to the unsatisfactory state of the ground from wet weather, it was difficult to get a good foundation for the machine upon which the rifle, a Whitworth, was placed. In spite of this drawback, at the appointed time all was ready, and the Queen, pulling the trigger by means of a cord, handed to her by Mr. Whitworth, scored a bull's-eye at 400 yards, 2¼ inches from the exact centre. The Committee of the National Rifle Association annually invited gunmakers to compete for the supply of the rifle that should be used in shooting for the Queen's Prize. Mr. Leece, as Mr. Whitworth's representative, whenever he entered the competition was always successful. Mr. Leece was a good marksman. On one occasion, competing with a celebrated shot, he had hit the target five times in succession at 1,000 yards. They tied three times, and at length his adversary missed. Mr. Leece, making nine consecutive hits, won the prize. This was considered remarkably good shooting, especially as a strong wind was blowing at the time right across the range; also he was equally successful at a contest for a prize offered by the Marquis of Tweeddale, for combined accuracy and rapidity of firing. The muzzle-loading rifle was used, and Mr. Leece far outstripped all competitors in both respects. These and other incidents earned for him the highest encomiums of the press. In the words of one writer, "Nothing in all the stories of Robin Hood is half so good as this bit of real life." Among many other important events at which his attendance was required may be mentioned a visit he paid to Osborne, accompanied by Mr. Whitworth. Here they explained their principle of rifling to Royalty; and Mr. Leece had the honour of a short conversation with the Princess Royal. At another time he was present at a series of important experiments with their light field-guns, which took place at Versailles, in the presence of an assembly of distinguished officers of the French army. A similar meeting was also held at the camp of Chalons. Consultations with the executive of home and foreign Governments, experiments on land and sea, at Shoeburyness and Portsmouth, long journeys hither and thither, at all times and seasons, voluminous reports of his doings, occupied his time and energies for a number of years.

Mr. Leece, still applying himself to the great work of his life, was recently invited to be an Associate Member of the War Office Ordnance Committee, to improve the method of testing and of

treating steel, and the armament of the service. His practical suggestions seem to have been much appreciated by the Government, whose thanks he received for the assistance he had given them. He had several tempting offers of engagements, but he would not forsake the old firm, in whose service he worked with strict integrity and honour till worn out in mind and body. He had been for some time managing director of the company when, in consequence of a cold caught on a journey to Newcastle on business, his health began to fail, and he never really recovered.

Thirty years ago, when the science was in a crude state, Mr. Leece devoted much attention to photography; and he was joint-contributor of a Paper which was read before the Photographic Society. His experiments in photography were of great utility in the Whitworth Company's Works. Horticulture, especially the cultivation of roses, was another pursuit of which he was very fond, and in which he was no mean authority.

His illness at length put an end to his attendance at the works, to which he had devoted thirty-eight years of his life. At the advice of his medical man, he took a voyage to Australia, in the hope that it would restore him to health, and so enable him to resume his duties. But it was not to be. He died on the 13th of January, 1886, only eighteen days after landing at Melbourne, where his remains were interred.

In business energetic, painstaking, and, as we have said, strictly honourable, he won the esteem and confidence of his employers. In company he was unassuming, affable, and always ready to communicate the information he had acquired by his observation and experience. He was thus beloved by all who knew him, and by none will his loss be more deeply regretted than by his fellow-workers at Openshaw.

Mr. Leece was elected a Member on the 6th of May, 1879.

FREDERICK SWANWICK died on the 15th of November, 1885, at Bournemouth, at the age of seventy-five. He was for thirty-eight years a member of this Institution, having been elected on the 29th of June, 1847, and one of the last survivors of that eminent band of Civil Engineers of which the Stephensons, father and son, the Brunels, father and son, Bidder, Locke, Vignoles, the subject of this memoir, and others were amongst the most distinguished figures, and which, in the twenty years between 1830 and 1850, covered England with that network of

railways to which later additions bear no adequate proportion. If Mr. Swanwick's name be not so well known as some of those above mentioned, it is rather that he lacked the ambition than the ability to be distinguished; that he cared more to leave perfect than remarkable work behind him; that his extreme conscientiousness demanded that all his time should rather be given to the execution of the work in hand, than to the designing of unique structures for men to gaze and wonder at. But there can be no doubt that had exceptional conditions called for some new development of engineering skill, Mr. Swanwick's powerful mind, thorough acquaintance with the theory and practice of his profession, close application and absolute inability to be beaten, would have met and conquered those conditions, as the Stephensons conquered Chat Moss and the Menai Straits, or Brunel the passage of Plymouth Sound. Mr. Swanwick was born in Chester on the 1st of October, 1810. He was the youngest son of Mr. Joseph Swanwick, a man of keen and lively powers. His mother, Hannah Wicksteed, possessed vivid imagination and a keen sense of humour. As a boy, his intense earnestness in whatever matter occupied his attention, whether work or play, was one of his most notable characteristics, and to resist the impulse to a frolic was as impossible to him, at lawful seasons, as to neglect his duties at others. Frederick Swanwick was first sent to school with Mr. Bakewell, the Unitarian minister of Chester. Later on, the Rev. Dr. Hutton, of Leeds, his first cousin, though twenty years his senior, happening to see the lad, was much struck with his bright intelligence and evidence of high principle, and prevailed upon his father to let him take Frederick back with him, representing that it would be a privilege to have such a boy to keep up the tone of his school. He remained at Leeds for two or three years, and a mutual and very deep regard sprang up between master and pupil. In 1826 Mr. Swanwick went to the University of Edinburgh, and for one year attended the science and mathematical classes of Professors Leslie and Playfair. Other lectures, on more general subjects, also engaged his attention, and he was a frequent visitor to the museum of the University. In the autumn of 1827 he returned home, and became much interested in the construction of the Great Grosvenor bridge across the river Dee, boasting the largest span of any then existing bridge. Mr. Trubshaw, the builder of the bridge, was an acquaintance of Mr. Swanwick's father. He invited Frederick "to come within the gates and put his hand to work" if he liked. He did so with eager enthusiasm; here he met with an accident, striking his ankle with an adze, which kept him a prisoner for several weeks,

and left its mark and its consequences for life. He devoted two years at this time to the study of practical mathematics, and on the 5th of October, 1829, he was articled to George Stephenson, then engaged in constructing the Liverpool and Manchester Railway. He took up his residence, in common with other of the pupils, in Mr. Stephenson's house. The great engineer stimulated the ambition of his young people, and excited their emulation, by freely conversing with them on the principles of mechanics, examining them in their knowledge of practical science, and discussing questions of its application. "In these discussions the talk often grew exciting, and even feverish." The subject of this memoir formed the resolution to which he afterwards referred his professional success, "to accept all work sanctioned by his master, however apparently humble or undignified." He made for himself a strict rule of this, and no ridicule turned him from it; and to this he attributed his mastery of the minutest details of engineering work. As a child he had been indifferent to the opinions of his companions, when certain of his own course, and while he never retaliated or resented unkindness, he never yielded, and his buoyant spirits through life, under otherwise overwhelming difficulties, resulted from the indomitable will to pursue the straight course, and never weight his conscience with the knowledge of voluntary dereliction of duty.

In the same year (1829) in which he became Mr. Stephenson's pupil he also became his secretary, in succession to Mr. Gooch, and retained this office till Mr. Stephenson moved to Ashby de la Zouche. In this position he enjoyed the inestimable advantage, not only of watching the progress of the railway works, but the far greater one of being cognizant of George Stephenson's thoughts, experiments, plans, and modes of carrying out their results; and in those early days of railways Mr. Stephenson had not only to make the railway, but to design and make the machinery that made it, and the very tools that made the machinery. He had to begin at the very bottom, and himself build up all that was necessary for the undertaking—wagons, cranes, rails, keys, bolts, pins, everything. At the opening of the Liverpool and Manchester Railway, on the 15th of September, 1830, Mr. Swanwick drove the "Arrow," one of the engines that drew the first passenger train of engineering history.

In 1832, when Frederick Swanwick was at the very early age of twenty-two, Mr. Stephenson showed his remarkable confidence in his pupil's powers by entrusting him not only with the execution but with the selection of route—merely throwing out a

suggestion as to its direction—and the entire planning of the Whitby and Pickering Railway. It is indeed not certain that Mr. Stephenson had even seen the ground, but he had more important work on hand, and he gave his young pupil *carte blanche.* The line was a single one and for horse-power only. In 1833 the Act for this line was obtained, and in June, 1836, it was opened, and not till the opening day did George Stephenson see the railway that he had fathered, and completed by the hand of a pupil, with the most entire satisfaction.

But before this day arrived Mr. Swanwick was already engaged on the great engineering work of his life—the North Midland Railway, from Derby to Leeds, for which he obtained the Act in 1836, and which was opened on the 30th of June, 1840. This line pierces the backbone of England, tunnels beneath and amongst its Coal Measures, and crosses many times some of its principal rivers. The works were, therefore, exceedingly heavy, and Mr. Swanwick devoted untiring energy to make them permanent and absolutely sound, at the least possible cost, and without sacrificing reasonable beauty of design. It has been said, and with truth, that no railway works in England exceed those of this line in strength and durability. To these ends he never spared himself, nor, it may be added, his assistants, for he gave them credit—whether they all deserved it or not—for conscientiousness equal to his own. During the progress of the works on this line, and indeed during all his professional life, Mr. Swanwick worked very early and very late, and frequently night and day. It was his habit to do all possible travelling in the night, that he might be on the works or in his office during working hours. He would frequently rise at two o'clock to catch the early mail for some distant point of interest, be back at his office early, write, or direct his assistants and draughtsmen for some hours, drive to some other point in the afternoon, be back at the office in the evening and work till eleven or later—often alone—then walk home 3 miles, and begin again very nearly the same routine on the next day. He had a good constitution and was absolutely temperate, or he could never have weathered these continuous years of labour. During the progress of the works of the Clay Cross tunnel he would constantly snatch a hasty dinner, late in the evening, his gig waiting at the door, drive the 7 miles to Clay Cross, don his tunnel dress and surprise the night gangs by his appearance amongst them. His confidence in his lieutenants was always great, for he chose them with care and possessed that rare power of judging of character from expression

which seldom betrayed him; having chosen them with care he trusted them with completeness and devolved upon them the entire responsibility of their peculiar department. His contractors often thought him hard—but there was no real hardness in his dealings; he had to hold the scales between the Company and them, and he was absolutely firm in giving justice precedence to feeling.

With the preliminary survey of the North Midland Mr. Swanwick carried on also that of the York and North Midland under Mr. Cabrey, and the Sheffield and Rotherham, of which Mr. Robert Stephenson was Consulting Engineer, and Mr. Henry Vickers, of Sheffield—with whom Mr. Swanwick formed a strong and life-long friendship—solicitor. Of this last-mentioned railway Mr. Swanwick was also constructing engineer. This line was opened in 1839.

In 1836 Mr. Swanwick gave evidence before the committees of the House of Commons on all these lines and on that of the Derby and Birmingham also, and since his days were occupied in committee, his office-work had to be and was done during the nights. No one was more vigilant than he when necessary, and during many weeks before the 30th of November — the day for depositing railway plans with the Board of Trade—Mr. Swanwick and his chief assistants would scarcely have their clothes off at all. Well do they all remember the toil of the October, November and December of 1845 in particular, but, work over, by some happy chance the subject of this memoir had the very valuable faculty, to which probably he largely owed his own immunity from illness, of falling instantly asleep. In 1840 George Hudson, a draper of York and a bold adventurer, became chairman of the North Midland, and extensive amalgamations were formed which resulted in the union of the North Midland, Midland Counties, Birmingham and Derby and Birmingham and Bristol Railways, under the title of the Midland Railway. Quarrelling and fault-finding became the order of the day, and in 1844 Mr. W. H. Barlow, Past President Inst. C.E., became Resident Engineer of this amalgamated company, and Mr. Swanwick took charge of its newly-projected lines, piloting them through Parliament and superintending their construction. Amongst these were the Nottingham and Mansfield, opened in 1848; the Nottingham and Lincoln; the Erewash Valley; the Pinxton and Mansfield; the junction line between the Midland and the Sheffield and Manchester at Sheffield, opened in 1847. Besides these lines which were all executed, Mr. Swanwick was engaged in preparing for several bills which were afterwards abandoned, though many of them, with more or less modification, have been since carried out.

Amongst these were the Worcester and Shrewsbury; Sheffield and Bakewell; Severn Valley; Leeds, Wakefield and Midland Junction; Lincoln and Great Grimsby; Rotherham and Doncaster.

To form any adequate idea of the incessant toil, of body alone, which Mr. Swanwick underwent during the twenty years of his active professional life, it would be necessary to master the indirect evidence of his note-books, letter-books and accounts, for he kept no journal or diary. These, however, even without mastering them, indicate sufficiently his incessant activity; the almost inconceivable distances he compassed in each twenty-four hours, his various offices, London, the different works in progress, and his home for brief intervals, witnessing his active, necessary and useful presence at what seemed wonderfully near the same points of time.

Of his life, after retiring from the practice of his profession, this is not the place to speak at length, but it may briefly be said that it scarcely slackened in activity more than increasing years rendered necessary. His time and a most generous purse were always at the service of the public—especially in the neighbourhood of his home—in furthering all thoroughly useful work; he was an earnest philanthropist, though anything but a sentimental one; unsparing in his contempt and horror of mawkish sentiment, and debilitating and demoralizing alms-giving; but for hospitals, schools and institutions of a still higher educational aim he would lend his whole personal help and influence, and was always in the van.

As before remarked, Mr. Swanwick was a man of no frivolities and no personal indulgences, but he was genial in an unusual degree, with the buoyant and happy spirits of a child; the result of good health and a "conscience void of offence." His hospitality was unbounded and proverbial, and the home-sick young pupil found under his roof a joyful and kindly welcome that soon made it a home, and that cheered many a Sunday and holiday that would otherwise have been a weariness to get through.

After Mr. Swanwick settled at Whittington, the master to whom he was so much and so justly attached, Mr. George Stephenson, also settled near Chesterfield, at Tapton Hall, and their relations were of the most happy and cordial kind during the remainder of Mr. Stephenson's life. The latter died on the 12th of August, 1848, but his neighbour and pupil arrived, after an absence from home, just too late to follow him to the grave. On one occasion Mr. Swanwick invited Mr. Stephenson to meet Mr. Emerson at Whittington. A meeting which Mr. Emerson so greatly enjoyed, that he said "It was worth while to cross the

Atlantic, if only to see Stephenson," of whom he spoke as "a man of such native force of character and vigour of intellect."

Mr. Swanwick was, by education, a Unitarian, but he was no sectarian; he was, indeed, far above that, he was a practical Christian, consciously or unconsciously—who can tell?—following as closely as man can, the leading, the teaching, and the example of Christ; brave, faithful, loving, single-minded, and pure in heart and in life; courageous and unflinching in the performance of duty; absolutely unselfish and devoted in his personal relations, neither saying nor allowing to be said to him, an unkind or malicious word of any one, while avoiding equally, on the other hand, the semblance of flattery or adulation; a promoter of all innocent and wholesome pleasures; a man who held his substance in trust for those who required it more than he did; a man, in short, admired, respected, and loved by every one who knew him.

SILVIO BONAVIA was born on the 30th of March, 1852. He commenced his career in 1863 as an apprentice in the Royal Engineering Department at Malta, where in 1868 he was appointed Foreman of Works, while so employed attending a four years' course of lectures in the Malta University. In August, 1874, he obtained the Government warrant of "Perito," (literally "expert"), a profession by the members of which all works of construction in Malta are designed and executed, and all sorts of surveys and other engineering work carried out. After obtaining his warrant, he applied himself specially to sanitary engineering. On the 1st of May, 1877, he was appointed one of the advising engineers of the Malta Sanitary Office, and while in that position designed, and for the most part directed, the re-modelling of drainage and other sanitary improvements to more than two thousand dwellings, houses, and other buildings, among which were the Governor's Palace, Orphan Asylum, Cospicua Market, Government Primary, Infant and Secondary Schools, Monte di Pietà, &c. In October, 1881, he was appointed to give lectures on the Sanitary Building Law; on the 10th of May, 1881, he was transferred to the Public Works Department, where he remained until his death, and where, among many other duties, he had charge of the Branch "Roads, Streets, and Bridges." In this capacity he designed and executed many works, and was engaged in the direction of the lowering and deviation of the present awkward approach to the town of Valletta from the Grand Harbour. He died on the 9th of May, 1886, after a very short illness.

Mr. Bonavia was esteemed one of the ablest, most useful, and most active Surveyors in the Department, and his early death was greatly regretted.

His connection with the Institution was of the shortest, having only been elected an Associate Member on the 1st of December, 1885.

SAMUEL PONTIFEX, son of the late Mr. Russell Pontifex, was born about the year 1816. After serving an apprenticeship of seven years to his father, who was in business as an engineer in Shoe Lane, London, he entered the service of the Chartered Gas Company, under whom he was for five years a Mechanical Inspector. He was then for six years Resident Engineer of the Winchester Gas-company. He vacated that appointment to become Superintendent of the Mains and Supply Department of the Great Central Gas-company, with which undertaking his connection endured until its absorption by and amalgamation with the Chartered Gas company, now the Gas Light and Coke company.

Mr. Pontifex subsequently established himself in business in Coleman Street, E.C., as a Gas and Water Engineer, in conjunction with a partner; and the firm had a very extensive connection, having, in fact, contracts with almost every lighting authority in the Metropolis. The business of late years had received a very considerable extension outside of the Metropolis, and had become well known and honourably respected throughout the United Kingdom.

In connection with suburban gas-companies, he took a very prominent part in the formation and establishment of the Barnet District Gas and Water company, of which he was to the last an energetic, zealous, and valuable member of the directorate. He died at St. Leonards, on the 23rd of March, 1886.

Mr. Pontifex was highly esteemed, and even affectionately regarded, as a genial and courteous gentleman, of high probity and honour, kindly and considerate, and ever ready to lend a helping hand, both in private and in business matters. To the day of his death he evinced a keen and appreciative interest in everything relating to the gas-industry, with which he had been so long and honourably associated.

Mr. Pontifex was elected an Associate Member on the 7th of December, 1858.

JAMES HARTLEY[1] was one of those important members of the community who, founding new industries, and thereby employing large numbers of men, utilize great treasure in capital and machinery. His achievements in glass-making were akin to those of the Bessemer's, Siemens's, Stephenson's, Whitworth's, and others in the profession identified with this Institution; the same qualities of force of will and strength of character inspired him in his struggle for success, and the same rewards of wealth, honours, and, above all, of public esteem, crowned his life's work.

He was the son of Mr. John Hartley, of Harborne, Staffordshire, and was born at Dumbarton in 1810. When he was only a few years of age his parents removed from Dumbarton to Nailsea, near Bristol, where his father, who was one of the most successful sheet-glass makers of that day, undertook the management of the Crown Glass Works. About ten years afterwards the family left Nailsea, and commenced the business of glass-makers at Smethwick, near Birmingham, in partnership with Messrs. Chance. Mr. Hartley won his spurs as an inventor and reformer, while a junior partner in this firm. He first distinguished himself in developing the manufacture of crown window-glass, and was the first to use sulphate of soda in its present form for the making of crown-glass. There being a heavy duty at that time (73*s.* 6*d.* per cwt.) it was important to manufacture it with as little waste as possible, for every particle of glass made had to pay duty. The thick and heavy centre, or bullion part of the crown table, had long been a source of trouble and annoyance and loss to manufacturers. It was formed by means of an iron bar, along which the glass passed during the process of blowing. Mr. Hartley discovered and substituted a thimble for this iron bar, and thereby reduced the size of the bull's-eye (as it was sometimes termed) to a minimum, and at the same time improved the quality of the crown-glass, which was then a beautiful article, and manufactured to perfection by the firm. Other manufacturers, seeing the great advantages and the savings accruing from the use of the thimble, arranged with Mr. Hartley, and paid him for licenses to enable them to work the patent.

The thimble plan had the drawback of being too small to produce large panes of glass, 5-feet diameter being about the largest size that could be made, and as the demand for larger sizes became more pressing on the manufacturers, a new kind of window-glass

[1] This notice is mainly taken from the *Sunderland Weekly Echo*, May 28, 1886.

was discovered on the Continent, or rather a new method of working the same material, *i.e.*, instead of making the "metal" into the form of a round table, it was made in the form of a cylinder, and, having an entire plain surface, it became much in demand for the larger windows. Messrs. Chance Bros. and Co., seeing that it was necessary to adapt their works to the new or "German sheet" process, sent their junior partner to the Continent to learn the process of making the glass in cylinders. His father having taught him to work at the different departments, Mr. Hartley had a practical knowledge of the business, and he soon made himself master of the new process, which was destined, not only to rival crown-glass, but entirely to supersede it. After he had gained sufficient knowledge, Mr. Hartley returned to Birmingham, bringing with him a full set of skilled sheet-glass makers, and for a time he superintended their operations.

The first piece of German sheet-glass made in England Mr. Hartley had cut into a square, and put before a picture, which is now in the breakfast-room at Ashbrooke Hall. This he has often shown to his friends as a specimen of workmanship and good quality, produced in those early days of the sheet-glass making.

Three years after the death of Mr. Hartley's father, in the year 1833, he settled at Sunderland and commenced a career of commercial and manufacturing enterprise which has identified him for all time with the history, progress, and prosperity of the borough. On a plot of ground at Millfield, afterwards known as the "New Town," which he purchased from General Beckwith, he commenced the erection of the glasshouses. Soon other houses were added, and the operations were extended until the works reached their present huge dimensions.

In these days of railways, it seems like looking back into the dim and misty past to think of the time when Sunderland newspapers were taken by dog-cart to be posted at Newcastle, and when there was no means of sending glass to London except by the collier sailing-ships. In the early times of the Wear Glass-works, Mr. Hartley found himself crippled by these transport difficulties, and he in a measure surmounted them by having a vessel specially built for carrying glass to London, which was kept going till the railway superseded it. For several years Mr. Hartley journeyed to London every six weeks to call upon glass-merchants, and was obliged to go there and back upon stage coaches, the single journey occupying two days and two nights. With this experience, it is not wonderful that in late years Mr. Hartley took a prominent part in extending railway facilities.

The duty on glass was continued till the year 1845, when it was repealed. This induced many people to go into the trade, and the number of glassworks quickly increased fourfold; but many of those who had so suddenly rushed into the manufacture of glass, found to their cost that the financial results were not what they expected, and after a few years the number of works was reduced to the point at which it had stood for many years before the repeal of the duty.

During these changes in the trade, Mr. Hartley daily worked hard to maintain his ground. He was often fifteen hours per day personally superintending the entire works, and it was no unusual thing to find him in the manufactory during the midnight hours. It was only a man of his pluck and determination who would have kept on; but he felt confident in his efforts, and in the year 1847 he became the inventor and patentee of a new kind of roofing glass, now known universally as "Hartley's Patent Rolled Plate;" the first railway-station in England glazed with it was that at Monkwearmouth. At first the trade refused to patronise this innovation, and would not order it; but Mr. Hartley was not to be beaten. He advertised his new discovery in "roofing glass" throughout the horticultural world, and soon it began to be used for greenhouses, vineries, &c. The trade were then willing enough to purchase that which they found was becoming a leading commodity throughout the country. Mr. Hartley, being the sole manufacturer, got a good price for the article—nearly three times its present value. By this means he was not only recouped for the capital sunk in making crown- and sheet-glass, but he made a large fortune, on which, many years ago, he retired from active work. The coloured glass manufactured by the firm has also a world-wide reputation. It may be mentioned that much of the glass employed in the erection of the Great Exhibition of 1851 was supplied by his firm.

In spite of the calls made by business undertakings upon his time, Mr. Hartley always took an active part in public matters in Sunderland, and his conduct in connection therewith was always such as to earn the respect of even his bitterest opponents, as well as the admiration of those on whose side he took his stand. His connection with the Corporation commenced in 1842, when he was elected a representative of the West Ward. He held that position for the next eleven years, and was elected Mayor for 1851–2. In 1851 the Borough Improvement Act was passed, and in its promotion Mr. Hartley took an active part. That valuable but costly Act vested in the Corporation the control of the sanitary arrangements of the borough, which it had not previously possessed, and the whole of

the township Boards, which had previously looked after the paving, sewering, &c., were incorporated in one body. In the same year the scheme for reconstructing and strengthening Wearmouth Bridge had also his active support. At the close of his two years' mayoralty in November, 1853, Mr. Hartley was elected an alderman for St. Michael's Ward, and held that position until 1874, when he resigned his connection with the Corporation.

In politics Mr. Hartley was a Conservative. Since 1845 he exercised great influence in the town, and during one period was one of its representatives in the House of Commons. In the year named he was instrumental in inducing Mr. George Hudson, the "Railway King," to contest the borough. At the general election of 1865, Mr. William Shaw Lindsay, one of the old members, having retired, Mr. Hartley and Mr. John Candlish were nominated in addition to the sitting member, Mr. Fenwick. Mr. Hartley's friends worked enthusiastically, and the result was that Mr. Hartley was elected as a coadjutor to Mr. Fenwick. At the general election of 1868 Mr. Hartley retired from parliamentary life, but until his decease he actively supported the Conservative party in the borough.

Nearly all the public offices that can be held by a citizen were filled, at one time or another, by Mr. Hartley. He was made a magistrate for the borough in 1841; he was also a deputy-lieutenant for the county, and had been chairman of the bench since the death of Mr. George Hudson. By virtue of his office as a deputy-lieutenant he was a member of the Sunderland Board of Guardians; and on the formation of the River Wear Commission he was made a member of that body, serving latterly as chairman of the Finance Committee. As one of the presidents of the Sunderland Infirmary Mr. Hartley took a considerable share in the management of that institution, to whose funds he was a large donor. During his first term of office as Mayor the Pensher branch of the North-Eastern Railway was opened, and shortly afterwards he became a director of the Company, which position he held till his death.

This typical English citizen and man of worth died suddenly on the 24th of May, 1886, at a time when arrangements were in progress publicly to acknowledge and commemorate his life of usefulness, by presenting his portrait to the Sunderland Art Gallery.

On the news of his death the flags on the Sunderland public offices were lowered to half-mast, and resolutions of condolence were passed by the Town Council, the River Wear Commissioners, and the Borough Bank. His funeral was a quasi-public one, and was the occasion of the concourse of a great crowd of his fellow-townsmen.

Mr. Hartley was elected an Associate on the 5th of May, 1868.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Report of the Committee on a Uniform System for Tests of Cement.

(Transactions of the American Society of Civil Engineers, vol. xiv., 1885, p. 475.)

This Paper contains the recommendations of the Committee of the American Society of Civil Engineers as to the testing of cement, either natural or Portland. Under the term "natural cement" the lightly-burned American cements are understood, while "Portland cement" includes the heavily-burnt varieties, whether natural or artificial. The tensile-test is recommended, and the length of time allowed for the hardening of the briquettes is seven days, although where a known brand of cement is being used a one-day test may be allowable in cases of emergency; but only for the purpose of ascertaining whether the brand of cement is of its average quality. Although the crushing-test is of great value, the appliances are so cumbersome and expensive that the tensile-test is preferred. In cases of large contracts, however, crushing-tests may be made with the ends of the broken briquettes, these being reduced to 1-inch cubes by grinding and rubbing.

The sectional breaking-area of the tensile briquettes is 1 square inch. The tests are recommended to be made with cement that has passed through a No. 100 sieve (10,000 meshes to the square inch), made of No. 40 wire, Stubbs' gauge. They should, however, be repeated with the cement as supplied by the makers, in order to ascertain whether any deficiencies in the grinding may not be compensated for by superior quality of the cement.

To test whether a cement will crack, two cakes of 2 or 3 inches in diameter are made of the neat cement, about $\frac{1}{2}$-inch thick, with thin edges. The time is noted which these cakes take to acquire sufficient hardness for them to stand General Gillmore's test of a $\frac{1}{12}$-inch diameter wire loaded with $\frac{1}{4}$ lb. and a $\frac{1}{24}$-inch wire loaded with 1 lb. One of the cakes is immersed in water and examined daily for cracks at the edges; the other cake is exposed to the air, its colour affording some indication of the nature of the cement.

In making the tensile-tests with natural cements, 1 part of the cement is mixed with one part of sand; but with Portland cement 1 part of cement is mixed with 3 parts of sand, all materials being weighed. The tests should, in the first instance, be applied to the cement as sold; but should it prove unsatisfactory in this condition the coarser particles should be removed by the No. 100 sieve.

A Table is given showing the average minimum and maximum tensile-strength of cements of different kinds, also the standards of fineness and strength as adopted in Germany and Austria. In making the tests the sand and cement, weighed out in the proper proportions, are mixed dry, and all the water is added at once, after which the mixing must be rapid and thorough. The resulting mortar is firmly pressed into the moulds with the trowel, without ramming, the moulds being laid upon glass or some other non-absorbent material. When sufficiently set the briquettes are removed from the moulds and covered with a damp cloth, until, at the end of twenty-four hours, they are immersed in water. Ordinary clean water of a temperature between 60° and 70° Fahrenheit should be used for mixing and immersing. The approximate proportion of water for Portland cement is 25 per cent., and for natural cement 20 per cent. where the materials are used neat. When the briquettes consist of 1 part cement with 1 part sand, about 15 per cent. of the total weight of the mortar will be requisite, and 12 per cent. when 3 parts of sand are mixed with 1 part of cement. Five briquettes are used for each test, only those breaking at the smallest section being taken. The briquettes are broken immediately they are removed from the water, the temperature of the testing-room being constant between 60° and 70° Fahrenheit. The stress is applied to the briquette at a uniform rate of 400 lbs. per minute; but with a weak mixture one-half this rate may be used.

Little importance is attached to the weight of cement; but the cubic foot is recommended as the standard unit instead of the bushel.

The setting of cement does not afford an indication of its ultimate strength.

In very important work it is recommended to take a sample from each cask.

For testing the fineness of the cement three sieves are used, viz.:—

No. 50 (2,500 meshes per square inch), made of No. 35 Stubbs' gauge wire.

No. 74 (5,476 meshes per square inch), made of No. 37 Stubbs' gauge wire.

No. 100 (10,000 meshes per square inch), made of No. 40 Stubbs' gauge wire.

For sand the sieves are two, viz.:—

No. 20 (400 meshes per square inch), made of No. 28 Stubbs' gauge wire.

No. 30 (900 meshes per square inch), made of No. 31 Stubbs' gauge wire.

The material used as sand is the crushed quartz used in the manufacture of sand-paper.

It is a commercial article, obtainable in fairly uniform quality. The degree of fineness recommended is such that the sand will all pass a No. 20 sieve, and be caught on a No. 30 sieve. No

natural sand has been found equal to the crushed quartz in sharpness and uniform hardness of particles. The moulds recommended are of iron or brass, wood being only suited for temporary use. The shape of the briquettes is similar to that adopted in Germany. Illustrations of the briquettes are given, also of several American testing-machines. The clips first used for holding the briquettes in the testing-machine caused the fracture to take place at one of the points of contact instead of at the smallest section. This took place especially when the briquettes were so hard that the blunt point of the clip could not imbed itself in the shoulder of the briquette. When the points of the clips were slightly flattened so as to allow a larger surface of metal to come into contact with the briquette, better results were obtained. The clips should be strong, and furnished with a strengthening rib. They should be hung upon pivots to avoid cross-strain upon the breaking-section. Machines with spring balances should be avoided, being liable to error.

The amount of material required for making five briquettes is about $1\frac{3}{4}$ lb. for neat cement, and for briquettes composed of 3 parts of sand to 1 part of cement, about $1\frac{1}{4}$ lb. sand and $6\frac{2}{3}$ ounces of cement.

W. F. R.

On Blast-Furnace Slag and Slag-Cement as compared with Portland Cement. By Dr. C. Schumann.

(Deutsche Bauzeitung, 1886, p. 14.)

The investigations detailed in this Paper were undertaken with the view of ascertaining what amount of importance may be attached to blast-furnace slag or slag-cement as an ingredient of mortar, especially as compared with Portland cement. Hard, vitreous slag is almost devoid of hydraulicity, even when finely pulverized, and the same may be said of the powder which results from the spontaneous disaggregation of certain kinds of slag. Where, however, the slag is granulated, that is, chilled in water, it hardens under water when mixed with lime. Such granulated slag has recently been ground with lime and other ingredients, and sold under the name of "pozzolana cement," although the term "slag-cement" would be more correct. In order to test the accuracy of statements which had been made respecting such cement, a quantity was obtained and subjected to examination. In making the comparative tests with Portland cement care was taken to use both materials of the same degree of fineness, the mortars were also of the same consistence, and were rammed into the moulds by a mechanical rammer, so as to secure uniformity. No expansion was found to take place with slag-cement mortars; but cracks due to contraction were noticed in the test-cakes.

In testing the porosity of slag-cement mortars, the cement was mixed with three times its weight of standard sand, and moulded

into cakes 0·59 inch (1·5 centimetre) thick. These were allowed to harden for seven days, either under water or in moist air, and were then subjected to a water-pressure of 16·4 feet (5 metres) for a week, the surface exposed to the water-pressure being 3·87 square inches (25 square centimetres). When allowed to harden under water, the slag-cement mortar allowed 0·0976 cubic inch (1·60 cubic centimetre) of water to pass, while the Portland cement mortar remained watertight. The slag-cement cakes, which had hardened in moist air, allowed 0·366 cubic inch (6·05 cubic centimetres) of water to pass, while the Portland cement cakes showed a filtration of 0·11 cubic inch (1·8 cubic centimetre).

The slag-cement sets very slowly—in twelve to twenty hours—and after the initial set has taken place, the increase in strength is much slower than with Portland cement. In seven days the strength of a mortar composed of three parts standard sand and one part slag-cement was 93·87 lbs. per square inch (6·6 kilograms per square centimetre), as compared with 248·22 lbs. per square inch (17·1 kilograms per square centimetre) attained by Portland cement mortar of similar composition. The crushing strength of the 1 to 3 mortar was 1,524·73 lbs. per square inch (107·2 kilograms per square centimetre) for the slag-cement, and 2,056·02 lbs. per square inch (200·8 kilograms per square centimetre) for Portland cement; both after remaining twenty-eight days under water. When exposed to the air for fourteen days, after having been immersed for a similar period, the difference between the two cements was still more marked. The tensile strength of the Portland cement was 516·30 lbs. per square inch (36·3 kilograms per square centimetre) as against 182·06 lbs. per square inch (12·8 kilograms per square centimetre) for the slag-cement. When a larger proportion of water was used in making the briquettes, the difference became still more marked. While Portland cement increased its strength 64 per cent. under these conditions, as compared with an immersion period of twenty-eight days, slag-cement lost 18 per cent. of the strength which it would have attained if kept under water for the whole of the twenty-eight days. This is regarded as a point of great importance in building operations.

W. F. R.

On the Employment of Iron and Steel in Construction.

By — Considère.

(Annales des Ponts et Chaussées, 6th series, vol. ix., 1885, p. 574, 1 plate, and 21 woodcuts; and vol. xi., 1886, p. 5, 1 plate, and 15 woodcuts.)

This elaborate communication is divided into three parts; the first treats of the properties common to iron and steel, and of the physical and chemical influences which modify them; the second

deals with the effects of shocks, and the third with riveted joints. The characteristic differences in the processes of the manufacture of iron and steel are first briefly described. Wrought-iron is defined as puddled metal, whilst steel is understood as steel produced by fusion; and then the different strains to which the metals may be subjected are fully investigated, and tabulated results of numerous experiments are given. In experiments on bars subjected to tension, two properties are investigated, namely, the resistance to tension, which measures the tenacity of the metal, and the elongation, which indicates its ductility. When the limit of elasticity has been exceeded, the elongation of the bar is more rapid, and at length a contraction occurs in some point of the bar, termed striction, where it elongates much more than elsewhere, and where rupture finally occurs. The elongation accordingly consists of two parts, one part proportionate to the length of the cylindrical portion of the test-bar, and the other solely dependent upon the form and extent of the striction; and the striction increases with the size of the bar, and its elongation does not bear the same proportion to the total elongation in different metals. As the joints are generally the weakest parts of iron constructions, the solid bars are rarely exposed to strains approaching their breaking-strain, so that the ultimate elongation of the bars is of little consequence compared with the elongation of striction in the weak sections. In comparing metals therefore, the measurement of the elongation of striction is the most important; and if the proportional elongation is desired, it should be measured independently of the elongation of striction, instead of taking the total elongation, as is usually done in France. The resistance to flexion of various kinds of iron and steel does not vary proportionately to their resistance to tension, and therefore ductile metals should not be subjected to the same strains in bending as in simple tension. The ratio of the resistance of flexion to that of tension has been found to be very high for soft steel, and very low for hard steel, which unexpected result is explained by the experiments, which show that striction and its elongation are very great for very soft steel, and very slight for hard carburetted steel, the elongation in the former being more than twenty times that in the latter. In hard steel, rich in manganese, its inferiority in resistance to flexion, as compared with tension, is much less marked; and it is found that steel rich in manganese has an elongation of striction from five to seven times greater than carburetted steel of equal hardness, and possessing the same tensional resistance. The results obtained indicate that the resistance to flexion depends upon striction, which varies greatly with the composition of the metal, and that the resistance of a metal to flexion cannot be deduced from its resistance to tension, or the reverse. Punching holes increases the resistance of the metal when the holes are very close together, for the punching flattens the adjacent sides and increases their resistance, as in wire-drawing, whilst reducing their limit of elongation. When the holes are at a certain interval, depending upon their size and the thickness of

the plate, the resistance is normal; but when the interval is increased, the resistance diminishes per unit of sectional area, for the metal adjoining the holes reaches its limit of elongation before the remainder of the section has nearly reached its limit of resistance. This result may be obviated by removing the skin of the punched holes, or by drilling the holes. As, however, the punched holes do not affect the resistance of the metal till the limit of elasticity has been reached, they do not in practice detract from the strength of metal structures, which should never be strained up to that limit.

The shock produced by locomotives passing over the joints of rails was measured on the Puy-l'Évêque and Figeac bridges. It was found that the wheel of a locomotive crossing the Puy-l'Évêque bridge at the rate of 31 miles an hour produced a pressure of about 13 tons on the top flange of one of the girders, which developed dynamical strains in the adjacent lattice bars of 1·59 ton per square inch in the normal section and 2·1 tons in the weaker parts. If, however, the shock had been produced in the centre of the interval between the connections of the lattice bars, instead of close to a point of connection, a tensional strain of 3·24 tons would have been produced in the lower fibres of the flange. The shocks are reduced by tightening up the fish-bolts. The dynamical strains produced can only be attributed to the weight of the driving-wheels, and the parts directly connected with them, without the intervention of springs. Both theory and experiment show that, in a railway bridge, an increase of the mass interposed between the rail and the girder increases or diminishes the dynamical strain on the structure, according as the portion of the girder which sustains the shock is more or less rigid than the permanent way. The strains of shocks at the joints of the rails are proportionate to the square root of the weight of the wheel with its connections; and the dynamical strains vary in proportion to the speed, and to the angle between the adjacent rails. The ends of rails, connected by fish-plates, tend to dip under the rolling load, and throw a strain vertically on the fish-plates, which in time, by wear and deflection, allow the rails a certain amount of play. This result explains the reason of the greater efficiency of new fish-plates, or of old fish-plates after being turned. Moreover, a considerable divergence of the upper sides of the fish-plates from the horizontal causes the rails, in deflecting under a load, to act as wedges and throw a lateral strain upon the fish-plates, which is resisted by the fish-bolts, but tends to produce a lateral deflection in the unsupported parts of the plates. This accounts for the fact that steel fish-plates are superior to iron ones, for the lateral strains which affect iron plates do not attain the limit of elasticity of steel. The support afforded to the rail at its extremity depends upon the distance apart of its two fish-bolts, and upon the slightness of the inclination of the upper sides of the fish-plates. With steel fish-plates, the fish-bolts might be placed further apart; and the adoption of steel rails admits of a modification of their form, so as to enable the upper sides of the fish-plates to approach the horizontal. When

the road is laid with longitudinal sleepers, and special care is taken to ensure an efficient bearing at the ends of the rails, it is far superior to a road laid with cross-sleepers, as regards shocks at the joints on iron structures; but unless a good bearing is secured, it is scarcely as good. As a ballasted road would not tend to reduce the shocks on a bridge, it is doubtful whether the increase in dead weight would be compensated by its other advantages. The worst form of roadway, as regards shocks, is where the longitudinal sleeper rests on the upper flange of one of the main girders, as at Puy-l'Évêque bridge, for in such a case the shocks are transmitted to the main girder without the intervention of any elastic support. The form of the main girder does not appreciably influence the dynamical strains; but as its several parts have to sustain them, it is advisable to adopt a trellis with large links, and to add vertical pieces, so as to reduce the strain per square inch on the diagonals.

Great differences of opinion exist as to the strength of riveted joints, and as to the proper proportion of the section of the rivets to the section of the plates. The strains are resisted generally by the adherence caused by the clip of the rivets, and not by their section; so that the adherence of the rivets is of far more importance than the strength of their section, especially as, according to the ordinary rules, the strain on the rivets would not exceed 60 per cent. of the strain on the plates. The adherence of the rivet was found by experiment to increase 40 to 50 per cent. when the temperature at which the riveting was done decreased from bright red to dull red; but below about 1,100° the adherence decreases with the temperature. In good riveted joints with drilled holes, the average adherence is from 5 to 6⅓ tons per square inch, and the resistance to rupture 19 tons per square inch of section. Machine-riveting gave results very similar to those with a hammer, where the plates were thin and the holes perfectly true; but in practice it is much superior, increasing with the thickness of the joints, the diameter of the rivets, the imperfection of the boring, and inadequate supervision, so that machines should be used wherever practicable. Steel rivets must be riveted up within much smaller limits of temperature than iron rivets, which is very difficult by hammering, but which can easily be accomplished with powerful hydraulic riveters. A fairly satisfactory rule for the diameter of rivets is that the diameter should not exceed 3·8 thicknesses of the plate for rivets with single shear, and 1·9 thicknesses for rivets with double shear; but it would be correct to increase the diameter, not merely in proportion to the thickness of the plate, but also according to the number of plates, which would be often impracticable in riveting with a hammer, but can be done when riveting-machines are employed. True holes form an important element in all good construction, and these are more easily attained by drilling than by punching.

L. V. H.

Russian Rules for the Use of Steel in Construction.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, 1886, p. 59.)

In July 1885 the Russian Ministry of Roads published a series of provisional regulations concerning the use of steel, of which the following is a summary:—

1. Steel, whether Bessemer or Siemens-Martin, may be used in all structures.

2. In view of the great sensitiveness of steel to mechanical working it is to be noted that—

(*a.*) Plates and other sections must be tempered, after rolling, by means of the sand-bath. Care must be taken that on leaving the rolls the metal is not below a cherry-red heat.

(*b.*) Holes must not be punched but drilled.

(*c.*) When worked cold the material must not be sheared, but cut with a chisel. The edges must be planed. All bending must be done hot, and provision be made for subsequent slow cooling.

3. The material must possess the following properties:—

(*a.*) It must contain 0·05 to 0·20 per cent. of carbon.

(*b.*) Except for rivets the tensile-strength of all kinds of steel must be from 25·4 to 29·8 tons per square inch, extension at least 18 per cent., and the contraction of area at least 36 per cent.

For rivets the tensile-strength must be from 22·2 to 25·4 tons per square inch, extension at least 20 per cent., and contraction of area at least 50 per cent. The percentage of carbon for rivets must approach the lower limit (see *a*). Extension and contraction of area are to be measured on test-pieces of 10 inches length. The test-pieces must be worked cold.

4. A strip of the metal 10 or 12 inches in length, heated to cherry-red, and then plunged into water at 85½° Fahrenheit, must not show any cracks when so bent that the inner faces of the bent-piece, at a distance from the angle of one and a-half time the thickness of the plate, are three times the thickness of the plate apart.

5. The permissible strain upon the material is as follows:—

	Tons per Square Inch. Steel.	Iron.
(*a.*) For bridges of less than 49-feet span, and also for roadway bearers (longitudinal and cross):—		
For tension and compression	4·4	3·8
,, shearing of rivets, fastening the longitudinal to the cross-bearers, and these to the main girders	3·8	3·2
,, shearing of rivets in the rest of the structure .	4·4	3·8
,, shearing of the web of a plate girder . . .	2·9	2·2
(*b.*) For main girders of bridges of from 49 to 95 feet span:—		
For tension (net cross-section, after deducting rivet-holes)	4·8	4·4
,, compression (after deducting half area of rivet-holes)	4·8	4·4
,, shearing of rivets	4·4	3·8

	Tons per Square Inch. Steel.	Iron.
(c.) For main girders of bridges of more than 95 feet span:—		
For tension (net cross-section, after deducting rivet-holes)	5·1	4·6
„ compression (after deducting half area of rivet-holes)	5·1	4·6
„ shearing of rivets	4·4	3·8
(d.) For wind-bracing of bridges of more than 95 feet span:—		
For tension (net cross-section)	6·3	5·7
„ compression (after deducting half area of rivet-holes)	5·7	5·7
„ shearing of rivets	5·1	4·8

Iron and steel may be used in the same structure, but with the limitation that in each member of a group of similar parts the same material is to be used. For instance, the top and bottom booms of a girder form such a group; the diagonals and verticals of a girder, the cross and longitudinal roadway-bearers, are other such groups.

The use of steel rivets is not compulsory with steel plates.

W. B. W.

The Influence of Holing upon the Strength of Wrought-Iron.

Prof. L. TETMAJER, of Zürich.

(Schweizerische Bauzeitung, 1886, p. 33.)

From the results of a series of experiments carried out at the works of Messrs. Escher, Wyss, and Co., of Zürich, by Professor Tetmajer on wrought-iron boiler-plates of first Low Moor quality, made by Grillo, Funcke, and Co., to ascertain the effect upon the strength of the material of drilling and punching holes, he draws the following conclusions:—

(1.) The relative strength of the different parts of a wrought-iron plate varies. In the middle of the plate it is greatest, decreasing equally towards the two edges. This difference is partially, sometimes wholly, concealed by the holing, and subsequent treatment of the holed plate.

(2.) With increasing strength extension in length and contraction of area diminish; the coefficient of quality remaining about constant. In the middle of the plate, where the puddle-bars forming the pile are most drawn out, the coefficient of quality is greater than near the edges.

(3.) By punching, the material loses in strength. The loss of strength increases with the diminishing size of the hole. With a hole of diameter equal to the thickness of the plate, the loss amounts to about 20 per cent. of the original strength.

(4.) By annealing a punched plate, the loss of strength, accord-

ing as it is great or small, may be either diminished or completely restored if $\frac{\text{diameter of hole } (a)}{\text{thickness of plate } (s)} = 1\cdot5$, the original strength of the plate may be restored by annealing; if greater than 1·5, the original strength cannot be regained by annealing, while if less than 1·5, the original strength may be exceeded by annealing.

(5.) By means of annealing, the original strength of punched plates may be increased 17 per cent.

(6.) By rimering out punched holes, the loss of strength caused by the punching may be partly or wholly regained. The limit at which the original strength of the unholed material can be restored by rimering, about 0·08 inch, lies approximately in the proportion of the diameter of the hole (d) to the thickness of the plate (s), $\frac{d}{s} = 1\cdot5$. As even in the proportions $\frac{d}{s} = 2\cdot5$, the rimering of 0·04 inch in some circumstances is not sufficient, in that case it is necessary, in order to remove the bad effects of punching, to rimer out still more, until the sides of the whole are clean and show no traces of the punch.

(7.) By complete rimering out of the damaged circumference of a punched hole (0·04 to 0·08 inch), the strength of the unholed material is increased about 8 per cent.

(8.) If the diameter of the hole is equal to or greater than the thickness of the plate, there is no measurable loss of strength by drilling.

(9.) Drilled material shows an increase upon the original strength of from 3 to 12 per cent. The increase in strength is greater according to the proportion of the diameter of the hole to the thickness of the plate.

(10.) By annealing the drilled plate, a further increase of strength is obtained. The more hurtful the influence of the drilling, the greater is the increase of strength by annealing. The effect of annealing a drilled plate increases with the diminishing proportions of the diameter of the hole to the thickness of the plate. By drilling and annealing, the strength of the undrilled plate is increased as much as 12·5 per cent., or on an average 10 per cent.

(11.) Rimering out a drilled hole is useless. On the other hand, filing out a drilled hole increases the strength of the drilled material. The increase in strength of the material of a plate with drilled holes subsequently filed out (increasing the diameter of the holes about 0·08 inch), as compared with a plate with holes drilled or punched, and rimered, is at most 3·6 per cent. Plates with holes drilled and then filed have a mean increase of 10 per cent. in strength.

(12.) The foregoing results only apply to material of the best quality.

W. B. W.

On the Amount of Pressure exerted by Water in the Soil.

By L. Brennecke.

(Zeitschrift für Bauwesen, 1886, p. 101.)

The Author gives the results of a number of experiments, which were undertaken principally with a view to determining the influence exerted by capillary attraction in diminishing the pressure of water in various kinds of earth, especially sand of different size of grain, and of clay, it being assumed that the water can only find its way by suffusion through the mass, and that there are no large fissures present.

Reference is made to various Authors as regards their opinion on this subject, and the amount of deduction which under circumstances may be made from the theoretical pressure of ground-water in designing lock-floors, &c.

An observation (recorded by Beer) in regard to a filter-basin at Magdeburg in 1880 is quoted, bearing upon the amount of frictional resistance to water-pressure offered by the ground, even where, as in this instance, of coarse gravel. The basin in question, 178 feet (54·24 metres) in breadth, had been constructed with a concrete floor of 1 foot 7½ inches (0·5 metre) in thickness, and was kept filled with water to counterbalance the pressure of the external ground-water. On the occasion mentioned the water was pumped out to a level of 2 inches (0·05 metre) above the floor, when a slight upheaval of a portion of the latter being noticeable the basin was quickly refilled.

The level of the external ground-water was 7 feet 10½ inches above the under side of the concrete floor, and the weight of the floor was equal to a column of water of 3 feet 9 inches high; therefore, supposing the full pressure due to the height of the ground-water had been active, it would consequently have required a depth of water in the basin of 4 feet 10½ inches, instead of 2 inches, to preserve stability.

Other examples of the varying resistances of different earths to water-pressure are mentioned, viz.: At the coal-mine, Wormrevier, some years since, when carrying out some shaft repairs with the aid of pneumatic pressure, on reaching a depth of 48 feet below the surface of the ground-water in a saturated clay-sand, an air-pressure of ¾ atmosphere instead of twice that amount was sufficient to exclude the water; and at the Rheinpreussen mine near Homberg, in 1865, the caisson was sunk with a pressure of only 2½ atmospheres to such a depth as was calculated to require a pressure of 8 atmospheres. In the latter instance, however, a sudden increase of the water-pressure led to a most disastrous accident by bursting the air-lock. It is suggested that the water was held back for some time by the thick beds of clay which it was known had been passed through, but finally found its way through these by channels around the outer skin of the caisson. In the previous case quoted,

the Author is of opinion that, as only half the calculated air-pressure was requisite, probably half the column of ground-water was supported by the air-pressure, and the remainder by capillary attraction.

Details are given of laboratory experiments upon sands of various size of grain, together with a number of formulas and Tables, giving the corresponding height of the capillary column.

D. G.

Measurement of Deflection of Bridges on Russian Railways.

By Emil Sokal.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, 1886, p. 116.)

On the railway from Kozlow to Rostow a bridge consisting of two openings of 350 feet, spanned by continuous braced girders, had been rather carelessly erected, and it was necessary to watch it, and take careful measurements of the deflection. Owing to the great depth of the river, to erect a staging underneath the girders was too extensive a work, and readings with a level not being considered satisfactory, the following method was adopted. An iron pipe, $1\frac{1}{2}$ inch in diameter, was carried along the outside of one girder, resting upon angle-irons riveted to the underside of the bottom flange of the girder. From this pipe—at each abutment at the pier, and at five intermediate points on each span—vertical pipes of the same diameter branched out, the joints being made absolutely water-tight. Inside and near the top of each vertical pipe was fixed a graduated glass tube, $\frac{3}{4}$ inch in diameter, the iron pipe being cut away on both sides, to allow of the height of the water in the tube being observed. The divisions on these glass tubes were such that the zero point in all was the same distance above the flange of the girder, and when this was horizontal, all the zero points were in a straight line. Before the bridge was loaded the apparatus was filled with water, the tops of the upright pipes were covered over, and the water was then drawn off until it stood at 0 at each of the glass-tube gauges.

On the bridge being loaded, the deflection at any point could be at once read off with great accuracy.

W. B. W.

Economical Bridge-Construction.

(Centralblatt der Bauverwaltung, 1886, p. 57.)

The Author gives details of the system of constructing wrought-iron bridges on wooden piers, claiming for this method that while far cheaper than entire construction in iron, it avoids the expensive

maintenance and renewal required for a timber structure, and is therefore more economical than either. The wooden piles, 14 to 16 inches square, are cut off to a short depth below the lowest water-level; and on this, with a lead packing or steel socket, and with a $1\frac{5}{8}$-inch central bolt, the iron piles, formed each of four angle-irons, are erected, with cross-bracing and horizontal stiffeners. The superstructure is formed of wrought-iron plate cantilevers, overhanging about 3 feet, the intermediate length of span varying as requisite. This system is suitable in all cases of fairly small or quiet streams or tidal estuaries. The strains are calculated for a dead load of 50 lbs., and a live load of 80 lbs. per square foot.

The example quoted is a bridge over the Havel at Hennigsdorf, of which the following are the dimensions :—

	Feet.	In.
Total length between abutments	115	2
Height from water-level to under side of girder .	10	6
Depth of water.	14	0
„ of piles below bed of river	19	9
Width between parapets	18	9

The cost of this structure was :—

	£.
Abutments	920
Superstructure, piers, and piles	750
	£1,670

By substituting piles for the masonry abutments, this might be reduced to about £1,200. Larger bridges of this type have since been constructed at Berlin and elsewhere.

P. W. B.

The Construction of Modern Suspension-Bridges.

By — DE BOULONGNE.

(Annales des Ponts et Chaussées, 6th series, vol. xi. p. 150, 5 plates.)

The subject is considered under four heads, namely: (1.) Old French suspension-bridges; (2.) American suspension-bridges; (3.) Special types of suspension-bridges; and, lastly, (4.) New French suspension-bridges. Seventeen bridges are referred to, and drawings of several of these are given. As all the principal parts of suspension-bridges are in tension, the additional material required in other bridges to prevent flexion under compressional strains is dispensed with, and materials possessing great tensional strength, such as iron wires, can be employed. Suspension-bridges are therefore lighter than other forms of bridges, and provide a cheap system for bridges of average size, and the sole expedient for spans of exceptional dimensions. In France, the erection of suspension-bridges has generally been dictated by motives of economy; and

there were two distinct old types, one with masonry piers strong enough to support the strain of one span without the assistance of the adjacent span; the other with light piers, supported by stays, in which the fracture of the cables and stays of one span would involve the fall of the whole bridge. This latter very cheap form of bridge was condemned in 1870. Three forms of suspension-cables have been used, namely, iron-wire cables, chains of wrought-iron links, and cables of thin bands of iron bound together. The first, being composed of a number of parts of great tensional strength, are light in proportion to their strength, and not liable to break from some invisible defect. The iron chains have less strength than the wires; an invisible flaw may greatly reduce their strength, and they are weighted by their necessary connections; but they are less liable to rust than the wires. Cables of bands have been only adopted at three bridges, and, whilst little stronger than iron chains, are specially difficult to erect. The suspension-form has been adopted in America for bridging large spans; and, to secure rigidity, the parapets have been made of iron girders, and straight cables have been carried out from the top of the piers to several points along the outer sides of the roadway. The girders diminish the deflection of the roadway, and also distribute the load on several tie-bars; and the stays not merely stiffen the portion of the roadway to which they are attached, but also, by reducing the span of the uncontrolled cable, add rigidity to the central portion. The roadway also in American bridges has been connected by cables to the lower parts of the piers, or to the banks on each side, where deflection from wind-pressure might be expected. This system had been previously adopted by Brunel for two bridges erected at Ile Bourbon in 1823. The Americans were the first to adopt twisted wire cables, formed of several strands, which possess great flexibility, instead of parallel wire cables. These twisted cables are generally anchored by passing each extremity through the smaller end of a piece of iron hollowed out in the form of a truncated cone, the wires being spread out at the larger end, and the spaces filled with lead. Cables with parallel wires, however, are still used when, as at Brooklyn, a large cable has to be formed consisting of a great number of wires.

Three bridges have been erected on the Ordish system, a special type, of which the Prague Bridge, erected in 1868, is the earliest example. The system consists in adopting a certain number of intermediate points of support between the piers by oblique chains, on which a series of straight girders rest, forming the bridge. Mr. Fink raised objections to the system, on the grounds that the curved chain, serving solely to keep the oblique chains straight, adds weight, and gives no support to the bridge; that the slightest defect in workmanship might be very serious; and that the bridge would cost more than an equally solid bridge on one of the ordinary systems. Another special type, in which the bridge was hung on each side from two sets of chains, one above the other, and connected by trellis-work, was erected in 1860 on the Danube canal,

and carried a line of railway. This bridge was subjected to such severe strains that it had to be taken down in 1884, owing to the breaking-weight of the chains having been so much overestimated that the coefficient of safety, which was intended to be 5, was actually only 3. That the defect in this case was due to errors as to the breaking-weight, and not to the system, is proved by the fact that another bridge of the same type, built over the same canal in 1864, has been quite stable. The re-introduction of suspension-bridges in France, after the system had fallen into discredit, dates from 1870. The earliest modern example of these bridges is the St. Ilpize Bridge over the Allier,[1] where twisted cables and oblique stays were first employed in France. Cables of parallel wires, cylindrical in form and bound by bands of iron wire at intervals, were too rigid to be rolled up or carried about. The first twisted cables in France had all the wires twisted in the same direction; but, though forming very regular and compact cables, their rigidity was even greater than the parallel wire cables. The Americans secured flexibility by forming their cables out of several strands made with a few wires each, but the interstices are so large as to favour rust. M. Arnodin has constructed cables in which each successive coil of wires is twisted in the opposite direction to the preceding one, whilst the curvature of all the wires is kept uniform, so that when the cable elongates under tension, all its wires are equally strained. This type of cable is very flexible; whilst its interstices, though from three to six times greater than in the simple cables, are not so large as to endanger the life of the cable. In recent French bridges, the anchorage of the cables has been effected as in America; but an alloy of 4 parts of tin, 5 of lead, and 1 of antimony has been used for filling between the wires in the conical hole, instead of lead. Very fusible alloys are too soft to form a solid anchorage; and alloys which fuse only at a high temperature weaken the wires. To obtain a long continuous wire, it is necessary to unite several separate lengths. Formerly the ends were bound together with fine wire, and at Brooklyn Bridge the ends were screwed into little hollow cylinders; but these joints increase the diameter of the wire at several places, and render the cable less compact, and therefore expose it to oxidation. To avoid this, Mr. Arnodin files the extremities of the wires obliquely, and solders them together; but though the joint is strong, the wire is somewhat weakened near it. To provide for renewals, it is necessary to support the bridge on a series of cables, as has been done at the Lamothe Bridge,[2] so as to be able to renew one cable at a time. Recent French suspension-bridges have been provided with iron or steel cross-girders, which last longer than wooden beams and are equally light; also with iron girders for parapets, which increase the rigidity of the bridge; and, lastly, with oblique stays, which not merely serve, as in America, to

[1] *Post*, p. 428; [2] *Ibid.*

diminish the deflections of the roadway under passing loads, but also support the weight of the roadway near the piers, of which St. Ilpize Bridge is an instance.

L. V. H.

The Suspension-Bridges of St. Ilpize and Lamothe.

By — Nicou.

(Annales des Ponts et Chaussées, 6th series, vol. x., 1885, p. 660, 3 plates.)

Suspension-bridges, though less satisfactory than fixed bridges, are nevertheless most valuable in cases where the small funds available for country roads render the adoption of any other form of bridge impossible.

The St. Ilpize Bridge carries the high road across the river Allier. It has a large central span, with an opening of 223⅔ feet between the cast-iron columns bearing the supports for the cables, and two side spans having a width of 49½ feet between the columns and the abutments. The piers and abutments are founded on the rock which forms the bed of the river. The bridge is 85¼ feet above the low-water level of the Allier at its centre, and has a width of 13 feet between the parapets. The two side spans, and similar lengths of the main span next the piers, are each supported by sixteen stays; the central portion only of the middle span, for a length of 124½ feet, is borne by the cables. To diminish horizontal oscillations, the cables and stays are given an inward inclination downwards of one-tenth from the vertical. The suspension- and anchor-cables, and the stays on each side of the piers, are connected to an iron pin, supported by two cast-iron sectors on the top of each pier. The cables and stays are formed of twisted iron wire. The suspension- and anchor-cables are each composed of three elementary cables, containing seven strands formed of nineteen No. 18 wires each. The three cables are fastened into a single triangular bundle along the whole of the central portion where these cables support the roadway. The stays consist of single strands of nineteen wires. The cables and stays are held at their extremities by castings, which are connected with the central pins by iron straps. The central portion of the roadway is attached to the cables by seventy-eight suspension-rods, 0·83 inch in diameter, encircling and fastened to the cable. The parapets consist of wooden trusses, 4 feet 7 inches deep, with iron tension-rods, strong enough to bear their own weight along the central portion of the large span borne by the cables, and two-thirds of the weight of the roadway as well along the rest of the bridge. The total cost of the bridge was £2,820.

The Lamothe Bridge, crossing the Allier, near the town of Brioude, is larger than the St. Ilpize Bridge, and has been

made strong enough to bear loads of 11 tons on a single pair of wheels. It consists of a single span, with a clear width of 377 feet between the abutments. The roadway is 18 feet above the low-water level of the river, and it has a rise of 2 feet 2 inches in the centre. The bridge has a width of 18 feet between the parapets, of which 13½ feet are occupied by the carriage-road, and 2¼ feet by a footpath on each side. Each end of the bridge, for a distance of 37 feet from the piers, is supported by sloping stays; whilst the central portion, for a length of 311 feet, is suspended from parabolic cables. The cables and stays, however, are not inclined from the vertical, as at St. Ilpize Bridge, for wind-bracing is provided in the roadway. The whole system is supported over each pier on an iron pin, 4¾ inches in diameter, borne by a cast-iron carriage on rollers. The two carriages on each pier are connected by an iron shaft, so as to keep them, and the cables they support, at the proper distance apart. All the cables and stays are formed of twisted iron wire; the suspension- and anchor-cables consisting of seven strands of nineteen No. 21 wires each, and the stays of a single strand of thirty-seven No. 20 wires each. There are five suspension-cables on each side of the bridge, hanging side by side; and twelve anchor-cables counterpoise the ten suspension-cables and eight stays at each end. The roadway is hung from the cables by strands of fifty-two No. 18 wires. The parapet on each side consists of an iron lattice girder, so as to relieve the bridge of its weight. The bridge cost £7,337. The improvements effected in these bridges, as compared with ordinary suspension-bridges, consist in the use of stays and of twisted wire cables, the design of the parapets, the independence of the suspension- and anchor-cables, and the facilities afforded for repairs. The stays increase the rigidity of the bridge by supporting the roadway just where the suspension-rods would be longest; and more stays might have been adopted with advantage for supporting a greater length of the Lamothe bridge. The use of stays was economical in the St. Ilpize Bridge, and was not costly in the Lamothe Bridge, as it dispenses with the longest suspension-rods and reduces the weight on the cables. The stays in these bridges are exposed to strains of 10 tons on the square inch, like the cables; but even if they were increased so as to reduce the strain to 6½ or 7½ tons, as would be preferable, the slight increase in cost would be amply compensated for by the greater rigidity of the structure. Twisted wire cables can bear a greater strain than cables of parallel wires; and though they are less easily mended than the latter, it is probable that their need of repairs will be much less, owing to the more even tension of the several wires, and owing to their much smaller exposure to oxidation. The parapets in these bridges no longer merely serve their primitive purpose, but increase the strength of the bridge, and in the St. Ilpize Bridge bear also a portion of the load. The independence of the anchor- and suspension-cables, and the employment of several separate cables, together with the method of attachment of the

suspension-rods as adopted at the Lamothe Bridge, enable repairs or the renewals of the cables or other parts to be easily effected without stopping the traffic. In conclusion, it is suggested that this cheap type of bridge might be readily adapted for the passage of the small locomotives of light railways for branch lines.

L. V. H.

The Luiz I. Bridge at Oporto.[1] By T. SEYRIG, M. Inst. C.E.

(Memoires de la Société des Ingénieurs-civils, Paris, 1886, p. 38.)

The river Douro would seem to constitute a fruitful site for the erection of great engineering works. After a lapse of eight years, the first celebrated bridge, with central arch of 525-feet span, and of great height,[2] has been followed by a second example, apparently similar, but really presenting many features of difference when closely examined. Its most notable peculiarity is, that a single arch of 566-feet span provides two separate passages in the same vertical plane, of which the upper road is at a level of 164 feet above the lower one. This somewhat mars the bold effect of the work, but it serves to solve the somewhat difficult problem of intercommunication between the different levels of the town. The Author, who designed both structures, gives a summary of the various plans submitted in competition for the later bridge, insisting on the propriety of endeavouring in such works to harmonize economy and the exigencies of good construction with pleasing and even artistic aspect. This attention to artistic effect he claims as a characteristic of the French school of engineering.

The arch of the Luiz I. bridge is so far the largest existing, and will doubtless remain so until the completion of the Forth bridge. It weighs, with its two roadways, about 20 tons per lineal metre of span (6 tons per foot). The arch rests on rollers, and its form is the opposite of that of the earlier bridge; that is to say, it is narrowest at the crown, instead of being crescent-shaped. The theoretical considerations which led to this change are discussed at length by the Author, but the principal reason was the obligation of allowing the lower roadway to pass between the springings of the arch, while assuring the transmission to the masonry piers of the wind-stresses—that is to say, without interrupting the continuity of the cross-bracing. This difficult condition is asserted to have been satisfactorily met.

The width of each roadway is 26 feet 3 inches; the upper road is at a height of 204 feet above the river; it is paved with wood and is laid with a tramway. The lower road is macadamized.

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[1] An illustrated description of this bridge will be found in 'Engineering' for July 7, 1886.

[2] Minutes of Proceedings Inst. C.E. vols. li. p. 302; and lxiii. p. 177.

The total weight of metal in the structure is about 3,200 tons, and its price will amount to nearly £100,000.

The most important part of the Paper relates to the mode of erection. The Author adopted a novel system, consisting in the employment of wire cables, by which the various parts were raised from barges moored in the river below, and assembled in their proper positions by manœuvres executed entirely from the side piers. This funicular system resulted at once in safety, rapidity, and great economy.

The ironwork was constructed at the works of the Société de Willebroeck, and the excellent workmanship conduced greatly to render the erection easy and economical.

T. S.

Removable Bridges for Railways. By G. Thareau.

(Le Génie Civil, vol. viii., 1886, p. 333, 6 woodcuts.)

This system of bridge, designed by Mr. Eiffel, consists of a number of similar trianglar pieces, formed of angle-irons joined together by gussets riveted in the workshop. The pieces are bolted together to form continuous girders up to a length of 148 feet; and, being made of steel, can bear a strain of 6⅓ tons per square inch of section. The triangles are isoceles, 20 feet long and 10 feet high, and weighing 802 lbs., and are the heaviest parts of the bridge. Each girder is terminated by a half-piece, 10 feet long, provided with an upright, and weighing 639 lbs. The ties are of an angle-iron form, 10 feet long, and weighing 386 lbs. The above pieces serve for the construction of three different types of girders, namely: a single girder, 10 feet 1 inch high, for bridges up to 49¼-feet span; a double girder of the same height for bridges not exceeding 98½-feet span; and, lastly, a double girder, 19 feet 4 inches high, for bridges of from 98½- to 147¾-feet span. The weight of these bridges varies between 13½ tons for bridges of 49¼-feet span, and 77⅓ tons for the heaviest form of bridge of 147¾-feet span. Owing to the small number of bolts required to connect the several pieces, the lightness and small number of the parts, and the simplicity of the joints, the erection of the girders is both simple and rapid, and can be effected on scaffolding or by rolling out. One of these bridges has been recently used for the passage of the Orleans railway across the river Oust, during the rebuilding of three bridges crossing the river. The same bridge was employed at the three sites successively; and the largest of the four spans, having a length of 88½ feet and weighing 33 tons, was put together and rolled out into position in twenty hours. This bridge bore the trial test-loads without any permanent deflection; it carried the traffic for about one hundred and fifty days altogether, and, like other bridges of this type, proved satisfactorily rigid. L. V. H.

Deep-water Wooden Trestle.

(The Railroad Gazette, N.Y., 1886, p. 243.)

The Dartmouth branch of the Intercolonial Railway, as constructed, avoids a long detour, by crossing a narrow strait in Halifax harbour. This is known as "The Narrows," and is about 1,500 feet wide and from 60 to 80 feet deep, for a distance of 650 feet in the channel where the line crosses, the mean rise and fall of tide being 6 feet and the current varying from 1½ to occasionally 3 miles per hour.

The bottom is composed of a bed, 3 feet in thickness, of compact gravel interspersed with boulders overlying the rock. The viaduct has a total length of 2,050 feet, of which 1,204 feet is on piling, 650 on the trestling under consideration, and the remaining 196 feet is occupied by a steel swing-bridge. The piling, where in deep water, was stiffened transversely by brace-piles, which were driven plumb and afterwards drawn over to a considerable angle and bolted to the capping. The pivot pier for the swing-bridge is of masonry, and has a passage for vessels of 85 feet clear on each side. The top portion of the masonry to a depth of 2 feet below low-water is laid in cement, thence to the bottom, about 33 feet, is laid without mortar, but constructed of large blocks accurately dressed and bedded. They were laid by a diver, the stone being conveyed to the site by a lighter and lowered by steam-winch. The time occupied in building the pier was seventy days, the same diver being employed throughout that work, and the cost £14 4*s.* 4*d.* ($23) per cubic yard.

The trestling across the channel is illustrated by diagrams. Each trestle-framing is composed of four vertical members, made up of two 6 inches by 12 inches timbers for the lower half, and single 8 inches by 12 inches for the upper; there is a raking strut of 6 inches by 12 inches (double) on each side, and the whole is braced by 6 inches by 12 inches horizontals and diagonals. The current being strong and the admixture of fresh water considerable, the attacks of worm were likely to be unimportant, consequently sawn hemlock was considered sufficiently durable for the framing below low-water level; above this white pine has been used. The trestles are 25 feet apart from centre to centre, and rest on a ballasted crib which had previously been lowered into place, and the height from the bottom up to rail-level at the deepest part of the channel is about 90 feet.

The crib foundation was prepared in each case by the diver; six squared timbers were lowered to him, and then bedded and brought to a uniform level, and filled in and about with stone. This operation occupied one diver from one and a-half day to six days, according to the configuration of the ground. The crib itself was then weighted with about 9 tons of stone and lowered to its place on the bed-logs; the lowering and adjustment of the cribs occupied about one and a-half hour each. For lowering each trestle, ropes were

attached to its base and then passed down to pulley-blocks secured to the crib, and thence passed up to the winch of the travelling derrick situated on the viaduct, so far constructed. To the lower portion of the trestle were affixed temporary ballast lockers for sinking purposes; these were laden with 10 tons of stone, and the engine being started, the trestle was drawn downwards, and led by the blocks rested in its proper place upon the crib; the trestle was then secured to the latter, by the diver, with strap-bolts. The operation of towing out, hauling down and securing the fastenings of each trestle was in general about one and a-half day.

The average cost of the trestling per bay of 25 feet, complete, ready for the rails was as follows, viz.:—

	£.	s.	d.	Dollars.
Timber	52	14	5	257·17
Ironwork	34	2	8	166·50
Crib-material and work	12	6	0	60·00
Framing (labour)	41	0	0	200·00
Stone-ballast	5	8	3	26·40
Diving work	22	2	10	108·00
Incidentals	6	10	10	31·93
	£174	5	0	$850·00

The number of trestled bays is twenty-five, making the total cost of this part of the viaduct £4,356 5*s.* ($21,250), or at the rate of nearly £6 15*s.* ($33) per lineal foot.[1]

Steam- instead of hand-pumps were used for supplying air to the diver, regularity of stroke being of importance for deep-water work.

The viaduct has been under traffic for nearly a year, and the passage of trains, drawn by two locomotives at a speed of 15 miles per hour, has hitherto produced no undue motion, nor settlement in any part of the structure.

D. G.

Italian Railway-Construction.

(Centralblatt der Bauverwaltung, April 17, 24, and May 5, 1886.)

It is especially in earthwork and tunnel-construction that Italian railway engineering presents characteristic features, more particularly in South Italy and Sicily, where large formations of shifting sand and clay and continual landslips are encountered, as well as crevasses and soil disintegrated by volcanic action and earthquakes. Although behind some other countries in the development of their railway system, the Italians have by no means copied the practice of other nations; but though still largely dependent on foreign material, have introduced distinguishing

[1] (?) £6 19*s.* 5*d.* or $34.—D. G.

features in design and practice, testifying to great inherent energy and resources.

The marked alternation, in the southern part of the peninsula, of dry and wet seasons, causes frequent landslips and drifts of loose soil; and consequently the foundation of embankments is a matter of great difficulty, often requiring piling and other preparations of the surface, with ample provision—by revetment walls, culverts, and tumbling bays—for the regulation of streams which vary, according to the season, from a rivulet to a torrent. The slopes of the banks have also frequently to be entirely cased in fascines and rubble, or the whole bank has to be interlaced with these; in some cases the bank is formed with internal cross-culverts and drains and masses of dry filling, to enable the unavoidable saturation to be dealt with.

In iron bridge-work, which is distinctly characteristic of French influence, lattice girders are most commonly employed, and are now largely manufactured at Castellamare. In bridges of more than one span, great insistance is made on the use of continuous girders.

The construction of some of the tunnels offers points of great interest. The Marianopoli tunnel, on the Santa Caterina and Rocca-palumba line (Sicily) is about 3¾ miles long, and passes partly through shifting sand and clay, and through hard clay, gypsum, and chalk. It was driven from five shafts, varying in depth from 300 to 820 feet, the daily advance at each point averaging 5 feet. The thickness of the lining (the crown, side-walls and invert forming a continuous curve) varies greatly with the different strata, and in many places counterforts are also necessary. The subjoined dimensions show the section of the tunnel:—

	Feet.	Ins.
a. Height from invert to rail-level	3	2⅛
,, ,, rail-level to horizontal axis	6	6¾
,, ,, horizontal axis to crown	11	5⅝
Total height, invert to crown	21	2½
,, ,, rail-level to crown	18	0⅜
b. Width at rail-level	13	10½
,, ,, horizontal axis	18	4½

	Feet.	Ins.		
c. Radius (1) crown . .	7	4¾;	arc subtended	57° 8′
,, (2) springing .	10	3¼;	,, ,, (each side) .	38° 50′
,, (3) side walls .	14	4½;	,, ,, ,, ,, .	29° 8′

(22° 36′ above, and 6° 32′ below, the horizontal axis.)

	Feet.	In.		
,, (4) invert . .	9	1⅞;	arc subtended (each side)	166° 56′

d. Points of intersection of radii on vertical centre-line:

	Feet.	Ins.	
Radii 1 and 2	3	2⅝	above the horizontal axis.
,, 2 ,, 3	1	10	,, ,, ,,
,, 3 ,, 4	0	7	below ,, ,,

e. Thickness of arch (all round) varies from 1 ft. 3 ins. to 4 ft. 6 ins.

Amongst recent performances of the Ferroux boring-machine is the Cocullo tunnel, 3,828 yards long, on the line from Rome to Sulmona. The tunnels on the Novara-Pino line are described below.

In permanent-way, flanged rails on transverse wooden sleepers are universally adopted: the rails (steel) weighing generally 73 lbs. per yard, in lengths of 29 feet 6 inches. On the South Italian railways still greater lengths are adopted. In 1883 there was in the whole country only one switch of English make; but in the Turin Exhibition of 1884 several were shown by the Alta Italia Railway Company.

Amongst the most remarkable lines recently constructed may be mentioned first the Benevento, Campobasso and Termoli Railway, branching from the Naples and Foggia line, through the high-lying districts of the Apennines to a more southerly point on the Adriatic coast. The length is 105½ miles, and the steepest gradient 1 in 40; the summit of the Apennine watershed is reached at San Giuliano (38 miles) at a height of 1,700 feet, the highest point of the line being 2,848 feet above the sea. Between Campobasso and Termoli the soil is frequently very treacherous, occasioning several slips in tunnels and earthworks; and at Casca-calende only a temporary wooden station was erected, as the whole site was in movement.

The Aquila, Rieti and Terni line, 64 miles in length, also traverses the Apennines, the steepest gradient being 1 in 28·5. The summit of the line is reached at Sella di Corno, 3,248 feet above the sea; from Antrodocco, in the Velino valley, the line rises 919 feet in less than 7 miles by zigzag curves, half of this length being in tunnel.

The third line across the Apennines, began in 1882, connects Rome with Sulmona, on the east coast, and has been constructed as a main line. Its length is 105 miles, and the works fully rival those on the St. Gothard line. This railway crosses two distinct chains of the Apennines, between which Lake Fucino is situated; the western summit of the line at the Monte Beve tunnel, 4,170 yards in length, is at a height of 2,625 feet, the eastern summit and watershed at 2,959 feet, being at the Cocullo tunnel previously referred to. The steepest gradient is 1 in 33⅓.

The remaining line of particular interest is the Novara-Pino railway, forming part of the main line to the St. Gothard, from Genoa and the west coast, and joining the Novara and Avona line at Oleggio. Passing along the east side of Lago Maggiore, it is joined by the Monte Ceneri line from Como to Milan. The line extends to the frontier, a length of 40½ miles, of which 8·39 miles are in tunnel. The steepest gradient is 1 in 129; and there are eighteen tunnels, two hundred and sixty-two small and twenty-two large bridges, including one over the Ticino near Sesto Calende with three spans of 263, 312, and 263 feet respectively.

The line is remarkable for the speed with which it was completed: the whole work having been finished in sixteen months.

One of the longest tunnels (Varalla-Pombia) 2,931 yards in length, partly in moraine, was pierced by hand-labour from the two faces and six shafts; the heading was completed in six and a half months, and the work finished within twelve months. The Laveno tunnel, 3,210 yards long, in chalk and dolomite, and for which access either by lateral or vertical shafts was impossible, was bored entirely by Ferroux machines from the two mouths: the time occupied being nearly fifteen months, the average daily progress being 6 yards, and greatest progress 7 yards. Both these tunnels are lined with brickwork.

P. W. B.

The Construction and Working of a Narrow-Gauge Forest Line.

(Centralblatt der Bauverwaltung, 1886, p. 64.)

This line, 2 miles 7 furlongs in length, was laid for the purpose of facilitating the clearing of a tract of pine forest in East Pomerania; economy in construction and working being the primary consideration. It is estimated that two and a half years will suffice to clear the land, and accordingly the line will at the end of that time be removed. No special rails are provided, but old rails are hired from the railway company. The line—which is of 2 feet gauge, and is worked by horse-power—commences at Gross Rambin station on the East Pomerian Railway; and following the existing line for about 1 mile, with a space of 11 feet 6 inches between the rails, it then crosses the Muglitz valley by a wooden viaduct 200 yards long, consisting of forty-five spans of 13 feet 1½ inch, with a width of 6 feet 10¾ inches between the parapets, and reaches the forest boundary. The steepest gradient is 1 in 40, and the sharpest curve 3½-chains radius. The rails are of flanged section, 21 feet 7½ inches long, laid on timber sleepers 4 feet 4 inches apart, 4 feet 4 inches long, split from trunks 8 to 10 inches square. On the first part of the line, and over the viaduct, the rails are jointed with fish-plates, but these are dispensed with on the remainder of the length. The formation-width is 6 feet 6 inches, and as the ground is firm sand, no special preparation is required; but the sleepers are well packed up with the sand, which affords a good tread for the horses.

No cranes are required at either end for loading and unloading any of the trunks, which vary in weight up to 2½ tons. At the forest end, the loading-place (varied in position as required) is formed by sinking the line about 1 foot 8 inches below the surface, and placing logs across this cutting, so that the trunks are rolled sideways on to the wagons. To bring the timber from the spot where it is felled to this loading-place, a cart is used, consisting simply of a pair of wheels with a small boss or drum on the axle; this is backed up over the felled trunk, nearly over the centre of

gravity, and reared up till the shaft is nearly vertical. Chains being then passed round the trunk, it is attached to strong pins on the drum; and the shaft—having a leverage of about 20 : 1—being lowered, the trunk, slung under the drum, is thus slewed up off the ground by two men, and carted to the wagons.

The wagons weigh 2½ cwt. each, and two are coupled to each timber-wagon, on which the trunks are lashed; the cross-bearer being pivoted in the centre and on rollers at each end, so that trunks 65 feet long can be carried round curves of 80-feet radius. The brake-blocks on each wagon are fitted with spiral springs, connected and worked by a side lever.

At the station the line is carried on staging, rising 1 in 60 alongside the transfer dock, to a height of 5 feet above the rail-level of the main-line siding: the platform of the dock, which is 13 feet wide and 130 feet long, being 1 foot 6 inches higher. Two sets of timber-wagons, carrying each 18 to 20 tons, could thus be unloaded at a time. The sides of the wagons being hinged, and chained across the top, cross-timbers are laid from the wagons to the platform, and the sides being let down, the trunks are rolled across to the level of the main-line trucks.

The wagons are allowed to come down to the station only between the times for the main-line trains; the daily average being six journeys each way. Each train comprising two sets of wagons, the daily freight is therefore 48 tons. The season extends from the middle of October to the end of May. The staff employed is twelve men and seven horses, viz., four men and four horses carting to the loading-place, three men in charge of the trains, with three horses, and five men unloading.

The cost of the undertaking is stated, as under:—

CONSTRUCTION.

	£	s.	d.
1. Easement on existing line, and land to forest boundary	15	0	0
2. Earthwork	72	10	0
3. Permanent-way, including siding at Gross Rambin	231	10	0
4. Muglitz Viaduct	100	0	0
5. Loading (transfer) dock	35	0	0
6. Ten sets of wagons	97	10	0
7. Signalling and telegraph	25	0	0
8. Engineering and miscellaneous charges	63	10	0
	£640	0	0

or about £224 per mile (*i.e.* without rails).

	£	s.	d.
Deduct estimated value of wagons and materials at end of two and a half years	150	0	0
	490	0	0
Add cost of taking up line	35	0	0
Net cost	£525	0	0

TOTAL EXPENDITURE ON WORKS.

	£.	s.	d.
1. Net construction, as above	525	0	0
2. Toll for use of main line, two and a half years at £35	87	10	0
3. „ Rails „ „ „ £57 10s.	143	15	0
4. Railway company's service, inspection, and maintenance of works at station, two and a half years at £30	75	0	0
	£831	5	0
or per load of 10 tons = 13 cubic yards	0	8	4
Add forest tax	0	0	3
Cost of transport to main line trucks	0	9	6
	£0	18	1

= 1*s.* 9¾*d* per ton, or 1*s.* 3½*d.* per cubic yard.

By the ordinary roads this cost would be 50 per cent. higher, and the rate of clearance much slower. The line was constructed in about six weeks, from the middle of December 1884 to the beginning of February 1885, and has since been worked most successfully, and without any accident.

P. W. B.

The most recently-constructed Narrow-gauge Railways in Saxony.
By C. KÖPCKE and P. PRESSLER.

(Der Civilingenieur, 1886, pp. 51–131.)

Those of the above which are described in the two articles to which this abstract relates are the Zittau-Reichenau and Markersdorf railway and the Klotzsche-Königsbrück railway, the former lying in the extreme easternmost portion of Saxony, and the latter commencing about 5 miles from Dresden, and running northwards from that city.

Zittau-Reichenau and Markersdorf Railway.—The line commences at Zittau, having a special station independent of that of the main line, which it immediately adjoins, and runs in an easterly direction to its terminus at Markersdorf. The gauge is 2 feet 5½ inches, and the railway, which to a great extent follows the course of the public road, has a length of 8·3 miles. Of this length 6·14 miles, or 74 per cent., is on gradients, and the remaining 2·16 miles, or 20 per cent., horizontal; and as regards its course, 2·36 miles, or 28 per cent., on curves, and 5·94 miles, or 71½ per cent., on the straight. The maximum gradient is 1 in 40, extending a distance of 1 mile, and least radius of curve 246 feet.

A section of the gradients is given, and the positions of the eight (including terminal) stations are shown on this and on a general plan. Cross-sections of the line and diagrams of the station yards, and also of the buildings and principal bridges, accompany the original. The least distance between any two stations is 0·69 mile, and the greatest 1·53 mile.

A Table gives the names of the stations, the length of their sidings, the steepest gradients and sharpest curves between them, and detailed prices of each, including platforms, goods-sheds, &c.

Particulars of dimensions and cost of each bridge, culvert, &c., and a special drawing of a Warren girder bridge over the River Kipper are given. It has two spans, viz., 74 feet 8 inches and 48 feet 5 inches, with a cylindrical pier of 9 feet 10 inches in diameter.

The girders are continuous, 7 feet 6 inches deep, and 11 feet 6 inches apart from centre to centre. The weight of the ironwork is 37½ tons, and the cost of the bridge, including erection, &c., £816 16*s.* 9*d.*, or £6 12*s.* 9*d.* per lineal foot.

The rolling-stock comprises two six-wheeled engines (weighing 15·3 tons each), ten passenger carriages, seven covered and twenty-eight open goods wagons. The cost of the line was as follows:—

	£.	s.	d.
Land	3,697	2	2
Earthwork, including rock and retaining-walls	5,627	16	9
Fencing, exclusive of that at stations	1	0	0
Level-crossings and road-bridges	976	10	10
Bridges and culverts	3,585	17	7
Permanent-way	11,806	3	0
Signals and cabins	212	14	3
Stations, platforms, &c.	5,793	0	5
Stream diversions, &c.	543	3	0
Rolling-stock	4,612	9	2
Superintendence	4,379	9	9
Sundries	107	0	11
Interest during construction	554	11	2
Total	£41,896	19	0

This gives a cost of £5,035 10*s.* per mile. The line was commenced in October 1883, and opened for traffic in November 1884.

Klotzsche-Königsbrück Railway.—The gauge adopted for this line is also 2 feet 5½ inches, that being deemed the most economical as affording the greatest facility for traffic purposes in proportion to the outlay.

It commences at Klotzsche, a station upon the main line of the Saxon-Silesian State Railway, and runs northward, following for a great part of its distance the main road through Hermsdorf, Ockrilla, &c., to its terminus at Königsbrück.

To demonstrate that in Saxony lines laid with the normal gauge are only suitable for the main through-traffic routes, and that for branch local lines the cost of construction and consequently the gauge must be considerably reduced to be remunerative, a diagram map of the Saxon State railway-system is given, showing by broader or narrower red and green lines on either side of each railway the original cost of construction and the amount of interest yielded in return.

A longitudinal section showing the gradients and position of stations is given, also sketches of the station-buildings, and principal bridges and cross-sections of the line. The whole length of

the railway is 12·12 miles, of which only 2·8 miles or 23 per cent. is on curves, and of these none are less than 328-feet radius, leaving 9·32 miles, or 77 per cent., straight. As regards levels, 6·72 miles, or 55 per cent., is inclined, and 5·40 miles, or 45 per cent., horizontal. The length of the steepest grade, viz., 1 in 60, amounts to 1·24 mile, or less than 10 per cent. of the whole.

A Table of the stations, of which there are nine, and their distances apart, varying from 0·43 mile to 4·52 miles is given, and details of their cost, including platforms, goods-sheds, &c.

Diagrams are given showing the methods employed in Saxony for transferring goods from the narrow to the normal gauge other than by actual unloading from one wagon to the other.

The first consists in lifting the body of the normal-gauge wagon and contents off its wheels, and lowering it on to a pair of four-wheeled narrow-gauge lorries, by means of overhead travelling cranes. The second method is especially suitable for goods requiring careful handling, such as pottery, glass, &c., and is effected by the aid of Langbein's patent rolling-cradles (*Rollschemel*). In this case the narrow-gauge line is laid for a wagon length down the centre of the normal-gauge track, their axes coinciding, but the rails of the former being at an elevation of about 1 foot above the latter. A cradle is then run into position under each of the wagon axles, and they are moved forward together until reaching a short incline (1 in 10 for a length of 8 inches), where the rails of the normal gauge drop about ¾ inch, whereby the axles of the wagon are seated on the cradles. Each cradle consists of a frame mounted on four wheels of 2 feet 11½ inches wheel-base, carrying a pivoted cross-beam, curved down at each end so as to support the rim of the wagon wheel. This latter method is recommended as much more practical and expeditious than the preceding, and is the only one in use on the railway in question.

Tables of the bridges, culverts, &c., with their cost are given, and a list of the rolling-stock, which includes four locomotives. The line was commenced in October 1883, and opened the following October.

The cost was as follows:—

	£.	s.	d.
Land	2,064	11	10
Earthwork, including rock and retaining-walls	3,853	14	4
Fencing, exclusive of that at stations	21	6	0
Level-crossings and road-bridges	871	16	4
Bridges and culverts	2,842	8	2
Permanent-way	16,386	11	2
Signals and cabins	313	2	4
Stations, platforms, &c.	7,152	2	2
River diversions, &c.	74	15	5
Rolling-stock	5,445	12	3
Superintendence	5,024	6	8
Sundries	163	3	10
Interest during construction	517	15	0
	£44,731	5	6

This gives a cost of £3,684 per mile.

D. G.

New Terminal Station of the Royal Hungarian State Railway at Budapest.

(Centralblatt der Bauverwaltung, 1886, p. 109.)

The network of the Hungarian State railways, which have their centre at the capital, Budapest, having increased to the extent of 2,663½ miles, the old terminal station became quite inadequate to the increased traffic; and accordingly in 1882 the reconstruction of the terminus was decided upon. The structure has recently been completed, after sixteen months' work, at an outlay of £425,000 (8½ millions of marks). The arched roof is in one span of 140 feet 6 inches; the height to the springing is 46 feet 9 inches. The length covered is 587 feet 7½ inches: the principals, resting on massive buttresses, varying in distance from centre to centre 27 feet 10½ inches, 30 feet 6 inches, and 49 feet 2½ inches, according to architectural requirements. The ribs are of wrought-iron, the tie-rods of steel, and the covering part glass and part galvanized iron. The weight of the superstructure is 266 tons, or about 18½ cwt. per lineal yard of the roof. In the erection, two principals were fixed and riveted up simultaneously, for which purpose a gantry 137 feet 9 inches wide, 92 feet high, and 78 feet 9 inches long, was employed, travelling on two lines of rails. The electric-lighting arrangements comprise seven hundred and twenty glow-lights and seventy arc-lights on Zipernowsky's system.

P. W. B.

Continuous Brakes on the Prussian State Railways.

(Centralblatt der Bauverwaltung, 1886, p. 24.)

The new government regulation, which came into force on April 1st, provides that in future all passenger-trains travelling at the rate of or exceeding thirty-seven miles per hour shall be provided with a continuous brake; and further, that in these trains the action shall be automatic in case of separation of the carriages. This provision thus agrees with the position taken up by the private railway companies, by whom the necessity of adopting continuous brakes had long since been recognized and acted upon. Nevertheless the new regulation is an important step; for it will soon become impracticable to confine the fitting of this brake merely to the express trains.

On some lines, separated however by intervening systems, the Heberlein brake has been adopted; but the impossibility, as matters stand, of running the trains over these intermediate lines considerably restricts its use. For passenger trains on the main lines Carpenter's pneumatic brake is generally employed, and its use has given great satisfaction in the results obtained in the com-

parisons which have been instituted. By October 1st of last year nearly one-third of the passenger trains on the State lines were provided with this brake; and to this date it has distinctly averted accidents in twenty-eight cases.

P. W. B.

A Standard form for the Treads and Flanges of Railway Wheels.

(Report of the Proceedings of the Nineteenth Annual Consultation of the Master Car-Builders' Association, June 1885, pages 16–115.)

A Committee appointed to recommend a standard form for the treads and flanges of cast-iron and steel-tired railway wheels made a report to the Master Car-builders' Association, under the presidency of Mr. Leander Garey, recommending a standard section, according to which the tire is $5\frac{1}{2}$ inches wide; the tread is cylindrical, 2 inches wide, joined to an inclined berm at the outer side, sloping $\frac{3}{16}$ inch in a width of $1\frac{5}{8}$ inch, and to the flange at the inner side by a curve of $\frac{5}{8}$-inch radius. The flange is $1\frac{1}{8}$ inch high, and has a total thickness of $1\frac{7}{8}$ inch, reckoned from the spring of the curve which starts from the tread. The proposed cylindricity of the tread gave rise to discussion, and the question arose whether the wear of the flanges was affected by this form in contrast with the ordinary conical section. Mr. Barr stated that in his experience on the Pennsylvania railroad of cast-iron chilled wheels, 81 per cent. of the wheels having cylindrical treads were condemned for worn flanges, against 20 per cent. of the conical wheels. Mr. Goodwin, on the contrary, stated that on the Lehigh Valley railroad, on which cylindrical cast-iron wheels had been in use since 1880, he found very few sharp flanges. An independent investigator had ascertained that only about 3 per cent. of the failures were caused by sharp-worn flanges. Mr. Wilder mentioned that of the wheels of half-a-dozen makers, which had been removed for various causes, 2·7 per cent. were removed for sharp flanges; of those of another half-dozen makers 8·2 per cent. were removed; and of those of a dozen other makers 20 per cent.—showing that the number of wheels removed for such cause bears a very small proportion to the whole number removed. Mr. Kirby pointed out that, in nine cases out of ten of sharp worn flanges, one wheel is softer than the other on the same axle; and Mr. Barr maintained that very few cases occur in which both wheels of a pair are worn sharp at the flanges—not 1 per cent. When one wheel was worn at the flange, the other was worn hollow at the tread away from the flange.

The question of the radius—$\frac{5}{8}$ inch—proposed for the junction of the tread and the flange was discussed; and although a radius of $\frac{1}{2}$ inch was advocated by some of the members, it appeared to be thought that with the larger radius, and even with a $\frac{3}{4}$-inch radius, the wheel could be more effectively chilled than with a $\frac{1}{2}$-inch radius.

The Committee also recommended that in fitting wheels on axles the standard distance between the backs of the flanges should be 4 feet 5⅜ inches; but that a variation be allowed from this dimension of ⅛ inch each way, making the maximum distance 4 feet 5½ inches, and the minimum distance 4 feet 5¼ inches.

The votes of members on these points were taken by letter-ballot. Of 108 members who voted, 53 voted in favour of the cylindrical tire, and 55 against it. But the number of votes cast in favour of it was 233, and 145 against it. The proposed standard section was not adopted.

Of the same number of members, 101 (carrying 368 votes) voted in favour of the proposed limits of variation, and 7 (carrying only 14 votes) against them. The limits were adopted.[1]

D. K. C.

Distant Signal operated by a Wire run through a Pipe filled with Oil. By William H. Dechant.

(Proceedings of the Engineers' Club of Philadelphia, vol. v., 1886, p. 341.)

In September 1885, a distant signal was required to protect a new crossing over the Little Schuylkill branch of the Philadelphia and Reading Railroad, between last Mahanoy Junction and Tamanend. The distance from the operating office to the semaphore signal post is 1,100 feet, and is part-way along a 4° and a 6° curve.

Instead of leading the wire through a long wooden box supported on small pulleys above the surface of the ground, as is usually done, it was decided to try the experiment of running the wire through a pipe filled with oil buried below the surface of the ground. A trench averaging 15 inches in depth was dug along a carefully laid out line; stakes 8 feet apart were driven along the bottom of this trench, so that their tops should come to a uniform grade line, which, in this case, was about 66 feet per mile; upon the tops of these stakes the ¾-inch galvanized iron pipe was fastened so as to hold it in as true a position as possible. A No. 15 iron wire was strung through each piece of pipe before screwing up, so that it might be used to draw the signal-wire through the pipe-line after all was laid. The pipes were all carefully examined and cleaned; a number had to be rejected on account of lumps of iron or galvanizing material obstructing the bore of the pipe. After the pipe was all laid the $\frac{3}{16}$-inch iron signal wire was stretched out with block and tackle to straighten it, and take out all the short kinks, and it was then pulled through into its proper position in the pipe by the smaller wire that had been strung through during the laying of the pipe. A small brass stuffing-box was

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[1] The subject of standard wheel-gauges formed matter for discussion by the same association in 1883. Min. Proc. Inst. C.E. vol. lxxvi. p. 421.

screwed to each end of the pipe, through which the ends of the leading wire were passed, to prevent the escape of the oil. The ends of the pipe being thus closed up, it was filled with common car-lubricating oil, mixed with about $\frac{1}{4}$-part of refined coal-oil to keep it from thickening in cold weather. The filling was done through a short upright branch attached to the highest end of the pipe.

The lever by which the distant signal is operated turns by the same movement four signal-boards on the tower; and during summer the usual counterbalance on the semaphore signal post adjusted to exert its least weight would operate the arm on the signal post, and revolve the signal boards on the tower; during colder weather the lubricator is possibly slightly stiffened, so that this same counterbalance barely turns the signal-boards in the tower and must have slight assistance.

The experiment has proved very successful thus far in the severe weather of this winter, and the apparatus has required no attention since being placed in position.

The apparent advantages of the plan are: (1) A very permanent and lasting arrangement; (2) Freedom from disturbance or accident to the signal wire; (3) Entire freedom from the difficulties caused by expansion if the pipe is laid below the frost line; and subjection to but slight changes from changes of temperature, if laid only 1 foot underground; (4) Suppression of the necessity to provide angle-fixtures to change the direction of the wire around curves.

The difference in cost of materials per 100 feet is but a trifle; being 5·38 dollars for the pipe-plan, and 5·42 dollars (22*s.* 5*d.* and 22*s.* 7*d.* respectively) for the wooden-box plan. The difference in labour would depend on the character of the ground; but in most cases it would be nearly the same.

The Monte Bove Tunnel.

(Giornale del Genio Civile, 1886, p. 68.)

This tunnel was commenced in February 1881, and the headings were finished in January of the present year. Its length is 4,312 yards; it was worked from the two ends only. The mean rate of progress was 7·22 feet per day from the two ends, or allowing for stoppage on holidays, 7·48 feet. The headings were driven by ordinary methods. The rock was very hard dolomite, which yielded a large quantity of water, amounting to between 6 and 7 million gallons per day, and drenching the men to such an extent that they could not work more than three hours at a time. The explosives used were dynamite gelatine in the advanced positions, and dynamite of the first quality in following up, in the proportions of 0·77 lb. of gelatine dynamite to 1·1 lb. of dynamite, or a total of 1·87 lb. per cubic metre of excavation. The tunnel is lined

throughout with masonry 19 inches thick. It is for a single line of way. Its greatest width is 16 feet 5 inches, the minimum allowable for ventilation in a tunnel of this length without air-draughts. During construction the ventilation was effected by Root's ventilators at each end, driven by steam-engines.

W. H. T.

Regulation of the Elbe-Navigation.

(Centralblatt der Bauverwaltung, 1886, p. 170.)

Considerable progress has been made during the last few years in the conservancy and improvement of the Elbe, particularly from the Saxon-Prussian frontier to Geesthacht, where the tides become perceptible, with a view to regulating the passage of vessels in all conditions of the channel. The present article reviews the recent operations of the survey, gauging, and levelling of the river, and the determination of the normal volume of water and velocity of the currents, which results have been published in a complete set of tables, charts and sections—a work unique in its way for the exhaustive scope of the systematic investigations here summarised.

P. W. B.

The Regulation of the Weser between Minden and Carlshafen.

(Deutsche Bauzeitung, 1886, p. 93.)

The opinion having been expressed that the construction of the ground-sills, or sunken weirs, for the improvement of the Weser between the above-mentioned places had not had the anticipated effect, and that the equalization of the inclination and the increased depth were due solely to the dredging operations and embankment works, the Author submits a section and tabular statement of levels of the river in its original condition (1878), and at the end of 1884 and 1885, from which the subjoined Table is summarised. From the data here given, it is shown that the dredging at the shallow points of the river has not been followed by any appreciable decrease of water-level, but on the whole by an increase, which is attributed to the construction of the transverse sills. While the dredging deepened the shallows to the required depth, the sills arrested the scour in the deeper parts, the effect of the backwater from each sill being appreciable up to the next sill above, so that the bed is in gradual process of regulation to the required depth. The specified uniform inclination on this section of the river is 1 in 2,180, and the depth 3·5 feet; and it will be seen by the extracts from the Table, showing the progressive state of the river at the three shoals, that this is in course of being satisfactorily attained.

Station. (Stations 330 yards apart.)	October 20th, 1878.				November 13th, 1884.							Nov. 13th, 1885.*	
									Effect of Operations to Date.				
	Level of Bed.	Water-level.	Depth.	Fall, 1 in	Level of Bed.	Water-level.	Depth.	Fall, 1 in	Bed-level.	Water-level.	Depth.	Water-level.	Fall, 1 in
			Feet.				Feet.				Foot.		
194 . .	350·02	353·96	3·94	2,940	349·37	353·64	4·27	1,400	−0·65	−0·32	+0·33	353·68	2,000
195 . .	349·70	352·98	3·28	340	349·29	353·23	3·94	800	−0·41	+0·25	+0·66	353·31	950
196 . .	348·40	352·80	4·40	5,170	349·07	353·01	3·94	1,470	+0·67	+0·21	−0·46	353·12	1,500
206 . .	348·02	352·51	4·49	8,570	347·99	352·25	4·26	1,800	−0·03	−0·26	−0·23	352·12	2,000
207 . .	349·03	352·08	3·05	760	347·91	351·85	3·94	810	−1·12	−0·23	+0·89	351·78	950
208 . .	347·98	351·66	3·68	780	347·50	351·60	4·10	1,300	−0·48	−0·06	+0·42	351·57	1,500
215 . .	347·15	351·24	4·09	1,090	346·47	350·90	4·43	900	−0·68	−0·34	+0·34	350·75	890
216 . .	346·82	350·40	3·58	390	346·46	350·56	4·10	960	−0·36	+0·16	+0·52	350·41	1,000

* Statistics incomplete.

P. W. B.

The Isthmus of Corinth Canal. By E. Pontzen.

(Nouvelles Annales de la Construction, 4th Series, vol. iii., 1886, col. 49, 1 plate.)

The isthmus of Corinth obliges vessels passing from the Mediterranean and Adriatic seas to the Archipelago and the Black Sea to make a considerable bend to the south. The idea of piercing the isthmus originated several centuries before the Christian era, and the works were actually commenced in the reign of Nero. The route across the isthmus will shorten the distance between the Pireus and Marseilles 11 per cent.; Genoa, 12·2 per cent.; Venice and Trieste, 18·4 per cent.; and Brindisi, 32·4 per cent. The probable traffic through the canal has been estimated at over 4,500,000 tons. The works were commenced in 1882, following the straight course indicated by the traces of Nero's canal. The canal has a depth of 26¼ feet, and a bottom width of 72 feet, like the original section of the Suez canal; but, as the Corinth canal has a total length of only 4 miles, the transit of vessels through it will be effected without the aid of passing-places. The principal mass of the excavation is concentrated within the central 2½ miles, and the greatest depth of cutting is 285 feet. Alluvial soil is mostly found for about two-thirds of a mile from each end; but the central portion consists of close chalk underlying hard calcareous conglomerate and compact sand, necessitating blasting and the use of the pick. The total amount of excavation is estimated at 13,000,000 cubic yards; and the portions executed at the end of 1885, and those to be carried out in 1886 and completed in 1887, are indicated in the longitudinal section. Depths of 33 feet are reached within 550 yards of the coast, both in the Bay of Corinth and the Gulf of Egina, and the dredging required at the entrances of the canal is not large. The west entrance, at Poseidonia, is protected by two converging jetties, forming a roadstead; and the east entrance, at Isthmia, is sheltered by a single curved jetty on the northern side. These three jetties, formed with natural blocks, are nearly completed. The canal will be open throughout, as the variations in the level of the sea at each end are very slight; and the only large work of construction is the metal bridge of 262-feet span, which crosses the canal at a height of 170 feet above the water-level, and will carry the Piræus and Peloponesus railway and the road to Corinth over the canal.

L. V. H.

Recent Extensions of the Prussian Canal-System.

(Centralblatt der Bauverwaltung, 1886, p. 121.)

Two important links in the development of the Prussian canal-system have recently been taken in hand, viz., the canal from Dortmund to Emden, and the improved connection of Berlin with the Upper Silesian district.

1. *The Canal from Dortmund to Emden* is designed to develop the communication between the Westphalian coalfield and the harbour at the mouth of the Ems,[1] and comprises (i.) the completion of the canal direct from the collieries and joining the Ems at Papenburg, and (ii.) the improvement of the navigation at Emden harbour.

The canal follows, at the outset, the Emscher valley to Henrichenburg, whence it is intended to construct a branch of about 5 miles to the Rhine; the length of this section being about 9¼ miles, with a fall of 45·3 feet. The section of 38 miles past Münster is unbroken by locks, but falls 50 feet to Bevergern, whence the previously existing Haneken Canal is followed as far as Meppen. The fall from Bevergern to Papenburg is 130·9 feet, and the distance 68 miles; the total fall from Dortmund to Emden being 226·2 feet, with twenty-six locks.

From Papenburg the Ems is navigable for the largest barges; but at Oldersum, about 6 miles from the mouth of the river, the channel becomes exposed to northerly storms; and from this point, therefore, a new cut, closed from the river by a lock, joins the new harbour, which, however, is yet unfinished, and is capable of considerable extension.

The dimensions of the work are:—

Canal.	Feet.	Ins.	Locks.	Feet.	Ins.
Width of bed	52	0	Length	220	0
„ at water-level .	78	0	Clear width of gates .	28	3
Depth	6	6	Depth on sill	8	3

The aqueducts, by which the canal is carried over the Lippe and Stever valleys, having also a depth of 8 feet 3 inches, the canal can at any time be dredged to this depth throughout. The navigation can be worked by steam-power; and when the harbour is completed, so that the coal can be brought direct from the collieries, the freight charges will probably be reduced to 2*s.* 3*d.* or 2*s.* 6*d.* per ton, as against 3*s.* 6*d.*, the lowest now charged.

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[1] Minutes of Proceedings Inst. C.E. vol. lxxxiv. p. 488.

COST.

Section.	Length. Miles.	Cost of Works.		Total Cost (including land).	
		Per mile.	Total.	Per mile.	Total.
		£.	£.	£.	£.
Dortmund to Henrichenburg	9¼	26,082	243,000	34,373	320,500
Branch to Herne (5 miles).	—	17,468	84,500	21,574	104,500
Henrichenburg to Bevergern	59½	18,354	1,092,500	20,608	1,228,500
		—	87,500	—	37,500
Bevergern to Papenburg	68	14,973	1,019,500	15,939	1,083,000
River (Ems) from Papenburg to Oldersum	19½	—	—	—	—
Oldersum to Emden	5¾	25,760	147,000	28,738	164,000
Emden Harbour	¾	—	295,000	—	295,000
Total distance, Dortmund to Emden Harbour.	162¾		2,919,000		3,233,000

2. *Improvement of the Navigation from the Oder at Fürstenberg to the Upper Spree at Berlin.*—The old Friedrich-Wilhelm Canal, constructed over two hundred years since, was till recently the only means of water-communication through this district; but the dimensions of the channel, as well as the locks, were considerably too small for present requirements; and in preference to reconstructing the whole work, it was decided to cut another channel, joining the Oder a few miles further from Frankfurt. The country traversed is easier than in the preceding case, and as the Oder does not take such large vessels as the Ems, the dimensions of the canal are smaller; the limit being for 400-ton barges:—

CANAL.

	Feet.	Ins.
Width of bed	46	0
„ at water-level	76	0
Depth	6	6

LOCKS.

	Feet.	Ins.
Length	180	0
Clear width of gates	28	3
Depth on sill	8	3

COST.

Section.	Length. Miles.	Cost per mile.	Total Cost.
		£.	£.
Canal from Furstenberg to Kersdorf Lake.	25½	15,295	391,000
Spree Improvement	14	4,508	62,500
Canal from Furstenwald to Seddin Lake (Upper Spree)	15	11,833	176,500
Total	54½	—	630,000
Average per mile	—	11,592	—

This navigation improvement will greatly affect the coalfields of Eastern Silesia, in bringing them into direct practical communication with Berlin.

P. W. B.

The Villoresi Canal. Experiments on the Flow of Water over Weirs.[1] By CESARE CIPOLLETTI, Engineer.

(Canale Villoresi. Modulo per la dispensa delle acque, esperimenti e formole per grande stramazzi a soglia inclinata ed orizontale. Milan, 1886, p. 66.)

The supply of water to this canal is, according to the terms of the concession granted by the Government, subject to the condition that a volume of water of 120 cubic metres (4,237·98 cubic feet) per second shall be measured and returned into the Ticino, before any can be taken for irrigation-purposes, and thus not interfere with existing rights down-stream.

To fulfil these conditions, the head-works are constructed in the following manner:—

A weir 289·44 metres (949·36 feet) long, and 4 metres (13·12 feet) high, is built across the river. Immediately above this weir, and on the left bank, is the entrance to the canal, a building provided with thirty sluices, capable of admitting 192 cubic metres (6,780·67 cubic feet) of water per second into the canal, of which 72 cubic metres (2,542·75 cubic feet) is the quantity granted by the concession for irrigation purposes, and 120 cubic metres to be returned as compensation into the Ticino. The 192 cubic metres of water per second is carried by a canal 600 metres (656 yards) long, and 52 metres (170 feet) wide, terminating in a basin, on the left bank of which are the buildings containing the head-sluices to the irrigation canal proper, as well as those of a small private canal, whilst on the right bank is the measuring-weir, over which the compensation-water is returned to the Ticino.

It was important, therefore, to establish with precision the coefficient of contraction, in order to fix the exact height at which the water should be maintained in the basin before admitting any water into the Villoresi canal.

As the mean discharge of the Ticino during the winter occasionally falls below 120 cubic metres per second, powers were granted by the concession to erect works at the outlet of the Lago Maggiore, in order to retain the waters of the lake at times when they are abundant, and regulate their flow into the Ticino.

The profile of the weir for measuring the 120 cubic metres per second is given at page 67 (this quantity, however, is reduced to 112 cubic metres, as 8 cubic metres are drawn off by the private canal already mentioned).

The crest, which is divided into thirty-six openings of 2·025 metres (6·65 feet) clear width each, by thirty-five partitions 0·08 metre (3·15 inches) thick, is 72·90 metres (239·11 feet) in length.

[1] A description of this canal will be found in vol. lxxxii. p. 416.

These partitions support a foot-bridge. The openings can be closed when required by boards placed vertically, with the bottom-ends resting against the up-stream side of the sill, which projects 12 centimetres (4·72 inches) above the level of the crest, and the top ends against the bridge. The total width of the crest is 1·85 metre (6·07 feet), of which 1·45 metre (4·75 feet) below the sill slopes 0·20 metre (7·87 inches), or about $\frac{1}{7}$.

The weir across the Ticino is 289·44 metres (949·36 feet) in length in the clear between the abutments, with horizontal crest, and curved breast and back, as shown in cross-section at page 68.

In order to establish the coefficient of reduction, to be used for calculating the discharge over the measuring weir, two measurements of the velocity in the canal, between it and the Ticino, were first taken by means of the Woltmann current-meter, the results of which were further controlled by direct measurements taken with the same instrument at the weir itself.

During these experiments, it must be observed, the whole volume of water brought down by the canal did not flow over the weir, part being allowed to enter the irrigation-canal.

The water is admitted into the canal from the basin by submerged openings, fitted with iron sluice-gates, and, previous to the experiments to be now described, their coefficients of contraction had been determined, and found to be between 0·72 and 0·74, or a mean of 0·73; so that, in order to ascertain the exact volume of water that was being admitted into the irrigation-canal, it was only necessary to measure the difference of the level of the water on each side of the sluices.

The first experiments were made on the 3rd and 4th of January, 1885, the level of the water in the basin being 0·538 metre (1·76 foot), above the crest.

	Cubic Metres.
The total flow in canal leading to basin (taken by actual measurement) being	65·754
Volume admitted into Villoresi canal	7·518
Quantity discharged over weir	58·236

The total clear width of overfall being 72·90 metres, the equation of the discharge would be—

$$Q = K\ 72 \cdot 9 \times H^{\frac{2}{3}} \sqrt{2\,g\,H}\,;$$

or

$$Q = K\ 214 \cdot 91\ H^{\frac{3}{2}}.$$

Assigning to Q and H their numerical values, viz., 58·236 cubic metres per second (already found by measurement) and 0·538, the value of the coefficient $K = 0 \cdot 685$ is found.

A second experiment, made on the 9th of March, gave the following results:—

	Cubic Metres.
Total flow in canal leading to basin (by measurement) .	128·803
Volume admitted into Villoresi canal	4·389
Quantity discharged over weir	124·414

Level of water 0·895 metre (2·93 feet) above crest.

Substituting these figures in the above equations, there would result—

$$Q = K\ 214 \cdot 91\ H^{\frac{3}{2}};$$

or

$$K = 0 \cdot 683.$$

The mean coefficient would therefore be—

$$K = \frac{0 \cdot 685 + 0 \cdot 683}{2} = 0 \cdot 684.$$

In determining the discharge by direct measurement at the weir, the velocity of the current was taken at different depths at five stations in two of the thirty-six openings. The depth of water in the basin above the crest being 0·835 metre (2·73 feet), the discharge through one opening was found to be 3·103 cubic metres, and of the other 3·194, giving a mean of 3·148, which multiplied by 36 gave a total discharge of 113·346 cubic metres, and this gives the following equation—

$$113 \cdot 346 = K\ 214 \cdot 91 \times 0 \cdot 835^{\frac{3}{2}};$$

or

$$K = \frac{113 \cdot 346}{163 \cdot 617} = 0 \cdot 692;$$

which differs only from the coefficients found by the previous experiments by 0·008, or about 1 per cent.

The coefficient of contraction for calculating the discharge over the river-weir was established in two different ways.

Taking advantage of two days in which the depth of water in the Ticino was alike; on the first it was allowed to flow entirely over the weir in the river, whilst on the second day part flowed over the measuring-weir, and part over that in the river, this being the most reliable way of determining the exact coefficient.

It was, however, necessary to take into account the water which found its way into the river, which was ascertained to be 4·50 cubic metres, 1 cubic metre of which was due to leakage of the dam, and 3·50 cubic metres from the four sluices which serve to empty the basin if required; when on the other hand, all the water flowed over the river-weir, it was found that there was a leakage of 2·09 by the head-sluices into the canal, so that there was a difference of 3·50 − 2·09 = 1·41 between a full basin and an empty one.

These experiments were made on the 27th and 28th of March, with an equal depth of water in the Ticino.

On the first day the entire volume of water passed over the weir, the depth above the crest being 0·458 metre (1·50 foot), whilst on the second, part was passed over the river-weir and part over the measuring one, with a depth of 0·77 metre (2·52 feet), corresponding to a volume of 99·517 cubic metres (3,514·54 feet), whilst the depth of water above the crest was reduced to 0·218 metre (0·71 foot).

The length of this dam being 289·44 metres (949·36 feet);

the leakage 2·09 cubic metres (73·81 cubic feet), and the coefficient K, the equation of discharge on the first day was—

$$K \times 289{\cdot}44 \times 0{\cdot}458 \times \tfrac{2}{3} \sqrt{2\,g \times 0{\cdot}458} + 209$$
$$= K \times 854{\cdot}535 \times \overline{0{\cdot}458}^{\frac{3}{2}} + 2{\cdot}09,$$

whilst on the second day the same discharge would be expressed by the formula—

$$K \times 854{\cdot}535 \times \overline{0{\cdot}218}^{\frac{3}{2}} + 99{\cdot}517 + 3{\cdot}50,$$

from which—

$$K \times 854{\cdot}535 \left(\overline{0{\cdot}458}^{\frac{3}{2}} - \overline{0{\cdot}218}^{\frac{3}{2}}\right) = 99{\cdot}517 + 3{\cdot}50 - 2{\cdot}09,$$

or $$K = \frac{100{\cdot}927}{178{\cdot}598} = 0{\cdot}565.$$

The measurements of the velocity of the current at the weir were taken with Woltmann's current-meter at nine different stations, and the discharge was found to be 422·542 cubic metres (14,922·49 cubic feet). The mean depth above the crest was 0·74 metre (2·43 feet), with a mean velocity of 1·972 metre (6·46 feet) per second. The depth above the crest to the surface of the comparatively still water was 0·928 metre (3·04 feet); the equation of discharge would therefore be—

$$422{\cdot}542 = K\ 289{\cdot}44 \times 0{\cdot}928 \times \tfrac{2}{3} \sqrt{2\,g\ 0{\cdot}928};$$

or $$422{\cdot}542 = K\ 854{\cdot}535 \times \overline{0{\cdot}928}^{\frac{3}{2}} = K\ 763{\cdot}868;$$

or $$K = \frac{422{\cdot}542}{763{\cdot}868} = 0{\cdot}553.$$

In a second experiment the velocity was measured at eleven vertical stations, and showed a total discharge of 239,771 cubic metres (8,465·75 cubic feet), with a depth of 0·494 metre (1·62 foot) over crest, and 0·628 metre (2·06 feet) in the comparatively still water up-stream; the mean velocity was 1·667 metre (5·46 feet); the equation in this case was—

$$239{\cdot}771 = K\ 854{\cdot}535 \times 0{\cdot}628^{\frac{3}{2}};$$

or $$K = 0{\cdot}563.$$

This latter coefficient only differing from that found by the first method by 0·002, or less than 0·4 per cent.

The coefficient definitely adopted was the mean of the three experiments, or 0·56.

From these it will be seen that there is a considerable difference in the phenomena of the movement of the water over the two weirs. In the first, with the inclined crest, the coefficient is comparatively high, notwithstanding that the flow is influenced by the thirty-five partitions; whilst on the other hand, it is below the average at the river-weir, notwithstanding its great length.

P. L. N. F.

Weir with Free Overfall and Constant Coefficient of Contraction for Gauging Water supplied for Irrigation.

By C. Cipolletti.

(Giornale del Genio Civile, 1886, p. 24.)

This Paper gives the results of investigations and experiments for measuring water delivered to cultivators for irrigation purposes from the Villoresi Canal, the discharge from each gauge being from 5 to 10 cubic feet per second. The problem to be solved was to determine the shape and disposition of a gauging weir such that, adopting the ordinary formula in its simplest form, $Q = K L H^{\frac{3}{2}}$, in which $K = m \frac{2}{3} \sqrt{2g}$ (m being the coefficient of contraction), the coefficient K remaining constant for any depth, H, over the weir and any length, L, none of the various sources of error would give a difference of more than $\frac{1}{2}$ per cent. between the real and the calculated discharge. There are eight circumstances which affect the discharge, namely :—

A. The form and disposition of the channel of approach.

B. The shape and thickness of the bottom and sides of the weir.

C. Distance of the weir from the bottom and sides of the channel of approach.

D. Velocity of the water in the channel of approach.

E. Ratio of the length of the weir to the depth of water flowing over it.

F. Conformation of the discharging-channel below the weir.

G. Place and method of determining the depth of water flowing over weir.

H. Accuracy of construction and precision in taking measurements.

The Author states in reference to the above heads :—

A. From experiments made on the Cavour Canal it appears that the channel of approach should be 66 feet long, and that this is sufficient to calm the water entering even with a fall of 19 inches. When this length cannot be obtained, perforated diaphragms should be inserted in the channel to still the water.

B. The water should approach the weir freely from all sides, as otherwise the coefficient will vary with the depth of the water. Experiments were made as to the effect of the width of the sill, and it was found that for depths of water less than 5 inches the width should not exceed one-tenth of the depth, and with depths of from 5 inches to 2 feet 2 inches it should not exceed one-fourth of the depth. Where the depth varies, the width should be that corresponding to the least depth. The upstream face of the weir must be in a vertical plane which extends to the sides and bottom of the channel of approach.

C. It appears from the experiments of Francis, when the sill of the weir is at a height above the bottom of the channel of approach equal to three times the depth of water over the sill, and the sides

of the weir are twice the depth of water over the sill from the sides of the channel, then the flow is not affected by the bottom and sides of the channel. If, however, these distances are reduced, the first to twice and the second to one and a half time the depth over the sill, the discharge is increased about ½ per cent.; and where the distances are further reduced, the first to twice and the second to the depth over the sill, the discharge is increased about 1 per cent.

D. It is well known that if the water before feeling the effect of the weir has a velocity of its own, the formula for discharge, instead of being $Q = K L H^{\frac{3}{2}}$, becomes $Q^1 = K\ L\ \{(H + h)^{\frac{3}{2}} - h^{\frac{3}{2}}\}$ h being the head corresponding to the initial velocity v and found by the expression $h = \frac{v^2}{2g}$. In practice, however, it is difficult to measure v. The channel may, however, be constructed in such a way that putting $\frac{Q^1 - Q}{Q} = r$, r shall not exceed any required fraction, and calling w the area of the channel of approach $= \frac{Q}{v}$, if the usual coefficient $m = 0 \cdot 62$ is taken, $w = 0 \cdot 50 \times \frac{L\,H}{\sqrt{r}}$; and the Author proceeds to prove that for $r = \frac{1}{100}, \frac{1}{200}, \frac{1}{400}$, w will be 5 H L, 7·07 H L, and 10 H L respectively; that is to say, that by making the area of the channel five, seven, or ten times that of the area of the weir, the error occasioned by neglecting the velocity of approach will not exceed $\frac{1}{100}$, $\frac{1}{200}$, or $\frac{1}{400}$, as the case may be, of the actual discharge. Comparing this with section C, making the bottom width of the channel 3 H and putting slopes of 1 to 1, $w =$ (L + 4 H) 4 H. It is shown later on that H should not exceed $\frac{L}{3}$, or putting L = 3 H, then $w = 0 \cdot 50 \frac{L\,H}{\sqrt{r}}$ gives $w = 21 \cdot 21\ H^2$, and $w =$ (L + 4 H) 4 H gives w 28 H^2, so that when the conditions of C are fulfilled the channel is so large, and consequently the velocity of approach so small, that the increase of discharge due to the latter is less than ½ per cent. of the total discharge.

E. This is the most important point of the question. In regard to it the experiments of Francis lead to the following conclusions. (*a*) The coefficient of contraction is made up of two parts, that due to the surface or horizontal contraction and that due to the sides. (*b*) The horizontal contraction of depths of water, varying from 1 inch to 20 inches, is constant, and its mean value is 0·623 with maximum of 0·624, and minimum 0·62, so that the possible error is less than 1 per cent. (*c*) The lateral contraction is also constant, provided that the length of the weir is at least three or four times the depth of the water; for shorter lengths the lateral contraction becomes less, because the contractions from the two sides interfere with one another. (*d*) In long weirs the side contraction is proportional to the depths of the water, and serves to diminish the effective length

by a mean value approximately equal to $\frac{1}{10}$ of this depth. Francis' formula is $Q = 0 \cdot 623 \, (L - 0 \cdot 10 \, n \, H) \, \frac{2}{3} \sqrt{2g} \, H^{1\frac{3}{2}}$, in which $H^1 = \{(H + h)^{\frac{3}{2}} - h^{\frac{3}{2}}\}^{\frac{2}{3}}$, and n is the number of sides which affect the contraction. When $n = 2$ this becomes $Q = 0 \cdot 623 \, (L - 0 \cdot 20 \, H) \, \frac{2}{3} \times \sqrt{2g} \, H^{1\frac{3}{2}}$. His experiments were confined to depths of from $7\frac{1}{2}$ to $18\frac{3}{4}$ inches, but by comparing the results obtained by other observers it appears that they are applicable to depths of from 3 to 24 inches, with a limit of error not exceeding $\frac{1}{2}$ per cent., provided that the length of the notch is not less than three or four times the depth. In order to get over the difficulty of the contraction varying with the depth, the notch should be made in the form of a trapezium; and the Author found that if the inclination of the sides was made $\frac{1}{4}$ to 1 the discharge within the above limits of depth would be given by the formula $Q = m \, L \, \frac{2}{3} \sqrt{2g} \, H^{\frac{3}{2}}$, in which it is only necessary to take m constant $= 0 \cdot 623$, the inclination of the sides balancing the side contraction.

F. The principal point to be attended to under this head is to ensure the free access of air under the water as it falls over the weir.

G. Several methods of measuring are described, the best being that by a suitably arranged hook-gauge with adjusting screw and vernier. With this it is easy to read to $\frac{1}{50}$ of an inch, and a practised observer can read to $\frac{1}{500}$ of an inch. A method is given for ascertaining the degree of accuracy required in reading the gauge, in order that the error in the discharge may not exceed a given ratio.

The Author states that if the works are executed with such reasonable accuracy as may be attained for a moderate expenditure, the discharge may be measured within $\frac{1}{2}$ per cent. As, however, the various errors which may creep in tend on the whole towards giving a discharge slightly in excess of that calculated, he considers that the coefficient m should be taken as $0 \cdot 63$ instead of $0 \cdot 623$, and he gives as his final formula $Q = 0 \cdot 42 \, L \, H \sqrt{2 \, g \, H}$ applicable to all cases within the following limits (the notch being made trapezoidal, as explained above): (*a*) H to be not less than $3\frac{1}{4}$ inches; (*b*) H not to be more than 24 inches; (*c*) H not to exceed in any case $\frac{L}{3}$ or $\frac{L}{4}$; and he then gives the following dimensions for the various parts in terms of H, when H is at its maximum value for the particular weir:—

$L = 3 \, H$ . . . (1); depth from sill to bottom of channel of approach $= 3 \, H$ . . . (1); distance from the sides of the channel to the sides of the notch $= 2 \, H$ . . . (1); thickness of the sill and sides of the notch $= \frac{H}{10}$ if $H < 4\frac{3}{4}$ inches, and $\frac{H}{4}$ if $H > 4\frac{3}{4}$ inches . . . (2); width of the bottom of the channel of approach $= 3 \, H$ . . . (1); depth of water in the canal of approach $= 4 \, H$; slopes of channel 1 to 1; area of water in the channel $= 28 \, H^2$; ratio of the

area of the notch to that of the water in the channel of approach $= \frac{3\,H^2}{28\,H^2} < \frac{1}{9}$; length of the channel of approach = from 30 H to 60 H. The dimensions marked (1) may be increased, those marked (2) may be diminished.

The Author then gives the application of these investigations to the case of the gauges of the Villoresi Canal, which are illustrated by drawings. There is also a table of discharge of weirs in metrical measures.

W. H. T.

The Port of Antwerp.[1] By MAURICE WIDMER.

(Annales des Ponts et Chaussées, 6th series, vol. x. 1885, p. 179, 1 plate.)

The six existing docks of Antwerp have an available length of quays of 7,371 lineal yards; and the quays along the Scheldt are 3,500 yards long, with a depth of 26½ alongside at low water, affording a total length of 10,871 yards of quays for sea-going vessels. This length will be increased to 14,534 yards about the end of this year, when it is expected that the new Africa and America docks,[2] in course of construction, will be opened. The excavations for these new docks have been accomplished partly by manual labour, the material being removed by wagons, and partly by excavators, which deposit the material behind the site of the walls; and it is proposed to complete the excavation, when the water has been admitted, by a screw suction dredger discharging its mixture of sand and water at the back of the walls. The walls have been built in an excavated trench, along the front of which a sheeting of piles and planks is driven. The brick wall is founded on a layer of rubble masonry, 6½ feet thick, and it is faced at the upper portion and coped with Belgian limestone. Details are given of the six graving-docks belonging to the port, which received two hundred and seventy-eight vessels in 1883. They are all closed by pairs of wooden gates; the largest has a length of 377 feet to the centre of the semi-circular end, a width at the top of 98½ feet, and an entrance width of 78¾ feet; it can be pumped dry in two hours. The receipts from the graving docks amounted to £10,050 in 1883, and the working-expenses and cost of maintenance were £2,400. There are nineteen cranes on the dock-quays, of which six are hydraulic, and six steam travelling 1½-ton cranes; but the latter are to be replaced by hydraulic cranes, which are more convenient and cheaper to work. Twenty-two large hydraulic travelling-cranes were put on the river-quays in 1883.[3] The great progress of the port within recent years is

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[1] Minutes of Proceedings Inst. C.E. vol. liii. p. 313.
[2] *Ibid.*, vol. lxxvii. p. 428. [3] *Ibid.*, vol. lxxiv. p. 312.

indicated by the following statistics. The total tonnage has risen from 2,779,956 tons in 1878 to 4,102,063 tons in 1884. This gain has been effected chiefly by the increased size of the vessels frequenting the port, for their number has only risen from 4,583 in 1878 to 4,809 in 1884, whilst their average tonnage has risen from 607 tons to 853 tons. The proportionate rise in the average tonnage has been greater with sailing vessels than with steamers; but whilst the number of steamers has increased from 3,045 in 1878 to 3,874 in 1884, the sailing vessels have diminished from 1,538 to 935. The tonnage at both these periods amounted to 315 tons per lineal yard of quay; but this average is sure to increase, as the river quays were not fully equipped in 1884. If, however, the same average is maintained when the new docks are opened, the time is not far distant when the tonnage of Antwerp will reach 5,500,000 tons.

L. V. H.

Economical Quay-Walls. By E. Pontzen.

(Nouvelles Annales de la Construction, 4th Series, vol. iii. 1886, col. 65, 1 plate and 1 woodcut.)

Though the cost of foundations by means of compressed air has been greatly reduced within recent years, there are cases where pile-work foundations are still advantageous. As quay-walls must be accessible for vessels, it is impossible to strengthen them like ordinary retaining-walls by a large batter on the face, by widening out the foundation at the outer toe, or by a mound of rubble in front. Accordingly, as far back as 1837, the plan of pushing forward the foundation by means of sloping piles was adopted at the Glasgow quays. A similar system, with improvements, has been adopted for the new Rouen quay-walls. The bed of the Seine, at Rouen, is about 32 feet below the required quay-level, and a layer of silty sand overlies the hard chalk, which is found at about 25 feet below the river bed. Instead of building a quay-wall, 33 feet high, on an unstable foundation, or carrying it down to the solid chalk, a wall, only 18 feet high, has been built upon piles sloping forward towards the front, and reaching down to the chalk. The thrust of the filling for the quay is kept off from the back of the wall by a mound of rubble stone, and by a layer of rubble stone resting upon a platform supported on piles, carried back far enough for the natural slope of the filling behind, going between the foundation piles under the wall, not to protrude in front of the face of the wall. The wall rests upon four rows of piles, of which the three front rows have a batter of 1 in 8; whilst the back row, and the four rows supporting the platform behind, are vertical. The lower part of the wall, for a height of 5⅓ feet, is composed of concrete, and is 11 feet wide, and the upper portion is built of rubble masonry, and has a width of 6½ feet at the

bottom. The wall has a batter of 1 in 8, and is faced with brickwork. The cost of this wall was about £24 per lineal foot. The latest design of quay-wall, which is being now built at Rouen for extending the quays, is similar in construction, but has been carried 3½ feet lower down, owing to the increasing draught of vessels coming up to Rouen, and in order to allow heavier weights to be placed near the edge of the quay. The concrete is deposited within watertight caissons of beech, 68 feet long, on the top of the piles. The wall is strengthened by iron tie-rods, at intervals of 35 feet, bolted to large blocks of masonry, placed about 66 feet back from the face of the wall. The last type of wall costs £25 8*s.* per lineal foot, exclusive of the dredging for placing the toe of the slope low enough for the anticipated deepening of the channel. The Author then compares the Rouen quay-wall with the New York quay-wall along the Hudson River, as executed since 1876. The New York wall is similar in type, being a slight wall of concrete and masonry, backed with rubble, and resting upon long vertical and sloping piles; but the piles are surrounded by a rubble mound, which projects in front of the wall, and the wall, though higher than the Rouen wall, is much thinner at the base, and its lower portion has been built with grooved concrete blocks. The top of the wall is about 35 feet above the bed of the channel, or about the same as at Rouen; but the piles are driven about 20 feet deeper at New York than at Rouen. The cost of the New York wall, after deducting expenses incurred in the removal of old works, was £39 18*s.* per lineal foot. It is suggested that the experience of Rouen shows that the rubble surrounding the piles at New York might have been safely dispensed with, that the projection of the rubble mound in front of the face of the wall is prejudicial to vessels, and that the cheaper wall of the Rouen type would have been better for New York than the type adopted.[1] It is considered, however, that for a long length of quay the concrete-block foundation employed at New York would be more economical than the concrete in mass deposited in frames. The above quay-walls are less durable than the Antwerp quay-wall, founded on firm ground, at a depth of about 60 feet below quay-level, or intermediate between the depth reached by the foundation piles at Rouen and New York. The Antwerp quay-wall, founded by aid of compressed air,[2] is strong enough to resist the thrust of the filling at the back, and also a surcharge of 5 tons per square yard on the quay; but it cost about £93 3*s.* per lineal foot, or nearly two and a half times the cost of the New York wall, and more than three and a half times the cost of the Rouen wall. The quay-wall at Ghent, founded on firm ground met with at a small depth, cost only £31 9*s.* per lineal foot. The concrete well-foundations of the

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[1] The type referred to was adopted, at New York, in places where the piles could not reach a firm stratum. ("Harbours and Docks," L. F. Vernon-Harcourt, p. 427.)

[2] "Harbours and Docks," p. 407, and plates 8 and 14.

Ninth Dock at Havre[1] proved an economical system under the special conditions of the site, having cost £34 13*s*. per lineal foot. Different systems are, accordingly, advisable under varying conditions; but the Rouen type of quay-wall has the advantage of enabling quay-walls to be extended at ports which, through want of resources, have hitherto possessed inadequate quay-accommodation.

L. V. H.

Harbour at Reunion Island. By P. Adigard.

(Revue Maritime et Coloniale, vol. lxxxviii. 1886, p. 472, 1 woodcut.)

The island of Reunion is devoid of natural harbours; and the Bay of St. Paul, though the most sheltered part of the coast, is exposed at times to a high surf, which rises suddenly and prevents access with the shore. The new harbour of Pointe-des-Galets is situated at the north of this bay, where the beach shelves so rapidly that depths of 14 fathoms are reached at 410 feet from low-water mark, and where an adjacent low-lying site was available for the construction of docks. The port, which is now completed, has been previously described;[2] and only the prospects of maintenance remain to be considered. The surf is so effectually arrested by the breakwaters, and the waves are so reduced on entering the harbour, that the outer harbour, designed for a stilling-basin, is utilized for commerce. The breakwaters have resisted the surf without injury. A trench, 33 feet deep, has been excavated in the south-west angle of the outer harbour, for receiving the sand and shingle which may be brought in stormy weather into the harbour, and from which it can be readily removed by dredgers without interfering with the navigation. No accumulations have taken place in front of the pier-heads; and a deposit of only from 13,000 to 15,000 cubic yards annually has occurred within the harbour. The access to the harbour is easy; and though it would be necessary for a vessel to make for the open sea when a violent storm has reached St. Paul's Bay, there is warning of the arrival of a cyclone some hours before it affects the bay. The port has been well equipped; and there is every prospect that its maintenance will be easy, and that it will confer great benefits on the commerce of those regions.

L. V. H.

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[1] Minutes of Proceedings, Inst. C.E. vol. lxxxi. p. 361.
[2] *Ibid.* vol. lxxx. p. 405.

French Steam Excavator. By G. Petit.

(Le Génie Civil, vol. viii., 1886, p. 257, 2 plates and 2 woodcuts.)

This new type of excavator, destined for the Panama Canal works, and tested in December, 1885, resembles the ordinary excavators in removing the earth by a chain of buckets. It differs, however, from them in having its supports at some distance from the edge of the cutting, in being able to excavate a slice of a cutting, 26¼ feet deep, 14¾ feet wide, and of any length, without shifting the roads, and in being provided with a transporter which, by means of travelling bands, can deposit the material in a mound at a considerable distance from the cutting. The excavator has two platforms; the lower one rests upon twelve pairs of wheels running on two parallel lines of way, 14¾ feet apart from centre to centre; and the upper one moves across the lower platform on sixteen rollers arranged in groups of four at each corner. The lower platform carries a steam-engine of 15 HP., which moves the excavator along, and also moves the upper platform across the lower one. The upper platform carries the excavating-machinery, consisting of a chain of twenty-three buckets, each having a capacity of 10⅔ cubic feet, which is worked by an engine of 100 HP. On commencing a cutting, the upper platform is brought to the near edge of the lower platform, and when the buckets have excavated to their limit of depth of 26¼ feet, the upper platform is gradually moved to the other side of the lower platform, traversing a distance of 14¾ feet; so that eventually the cutting, in level ground, has the section of a curved trapezium, 65 feet wide at the top, 14¾ feet at the base, and 26¼ feet deep, having an area of 137 square yards. Whilst the primary cutting is being excavated, a third line is laid, 14¾ feet behind the second line, to which it is connected by two S curves, and the first line is similarly connected to the second. The excavator is then shifted on to the second and third lines, and can excavate a second section of the cutting, having the form of a parallelogram 14¾ feet wide and 26¼ feet deep, and consequently a sectional area of 43 square yards; whereas the most powerful excavators recently made can only excavate an initial cutting of 38 square yards in section, and an additional section of 3½ square yards at each removal of the line. The upper platform carries a small transporter, which receives the material as it falls from the hopper, and discharges it on to the endless travelling band of the large transporter, which deposits it in a mound at a distance of 180 feet. At the rate of twenty-three buckets per minute, it was found that the excavation amounted to 438 cubic yards per hour; but the transporter used at the trials was unable to carry away this supply, which indicates the necessity of employing a transporter of greater capacity.

L. V. H.

The Badger Pumping-Dredge.

(American Machinist, vol. ix. February 6, 1886, p. 1, 2 woodcuts.)

A strongly-built barge has heavy framework, 25 feet high, erected on it and closed round, so as to provide two floors, the lower floor containing the boilers and machinery. Round the outside of the top of this framework, an overhanging road is formed, supported by projecting cross-beams and channel-iron brackets. Upon this road a truck with four flanged wheels runs, from which a dredging pulsometer steam-pump is suspended. An iron suction-pipe is fastened to the lower end of the pump, at the bottom of which is a digger, consisting of about eleven prongs fastened vertially round, and protruding beyond, a horizontal circular strainer. The digger, bearing the weight of the pump (about 2 tons), and having an oscillating movement imparted to it by the pump, loosens the material on which it rests. An iron discharge-pipe extends upward from the discharge of the pump, and, terminating with a curved neck, can deliver the dredged material into a central hopper at the top of the framework in the barge, from which it is conveyed ashore through a trough, or pipe, supported on a floating staging at intervals. The material, being delivered from the pump at a considerable height above the water, can be discharged on land 1,000 feet from the barge. The pump is worked by steam from a pipe carried right round the boat and provided with branches and valves at suitable points. This dredger, which has been working at Coney Island, has raised a maximum of 80 per cent. of sand; and its average is 50 per cent. of solid material out of the volume lifted. Under favourable conditions, it has a capacity of 10 cubic yards per minute.

L. V. H.

Rolling Bridge and Hydraulic Machinery of the Penhouët Lock at St. Nazaire. By R. Kerviler.

(Annales des Travaux publics, 1886, p. 1503, 2 plates and 1 woodcut.)

The rolling bridge over the Penhouët Lock was opened for traffic on the 1st of May, 1885; it has been constructed on a novel system, not previously tried in France, and it has proved so satisfactory that there is every prospect of this system being very serviceable. Swing-bridges take up a great deal of space along the quays, and impede the drawing of vessels through the locks. Rolling bridges have been adopted in England to avoid this inconvenience; but the plan employed for lifting the bridge, by raising each end alternately, in order to enable it to be rolled back on the roadway, is not simple. The Author accordingly decided to raise the bridge by a single press, on which it should be balanced, so as to reduce the movements in opening the bridge to two, the first lifting, and the second pulling the bridge back.

The accepted tender, out of the different systems proposed, fulfilled these conditions. On testing the bridge when completed in 1883, it was found that the tail end, carrying a great counterpoise weight, was not rigid enough, and hung down, so that it had to rise from 1 to 1½ inch on the rollers placed along the roadway, causing strains which the machinery was not calculated to bear. The bridge was accordingly stiffened so as to pass horizontally over the rollers, and it now works perfectly. The bridge crosses the large lock, 82 feet wide, in a single span; its total length is 141 feet, the traversing portion being 92 feet long, and the tail end 49 feet. The total weight of the bridge, including the additional stiffening pieces, is 300 tons, of which 80 tons are cast-iron kentledge. The bridge is 26½ feet wide to the outside of the main girders, which are 11 feet 10 inches deep, and carry at their lower portion the cross-girders, 2 feet 1½ inch deep, bearing two lines of way made flush with the roadway, so as to allow the passage of vehicles, and a footpath 2½ feet wide on each side. The bridge is lifted 3 feet 1½ inch, so as to clear the roadway, by a hydraulic piston 37½ inches in diameter, and 3¼ feet long, placed in a hole in the lock-wall. A cast-iron cap is fitted on the top of the piston, to which an iron cross-piece is fastened, 26¼ feet long, and 6½ feet wide, bearing at each corner a roller, on which the bridge rests when being lifted. The bridge is lifted slightly higher than the roadway; supports are then placed under the cross-piece, on to which it is lowered so that its rollers are level with the rollers along the roadway, and the bridge is rolled back, being drawn by chains worked by hydraulic machinery. The operation is accomplished in four minutes, with an average consumption of 330 gallons of water at a pressure of 50 atmospheres. The reverse operation of replacing the bridge across the lock takes less than four minutes. The machinery is simple, and easily accessible: its motion is gentle, and its control is easy. Omitting the foundations and masonry, which are very variable, the cost of this type of bridge, for spans of from 65 to 100 feet, carrying two lines of way, may be reckoned at £121 per foot of span, which, for a span of 82 feet, like the Penhouët Lock, would be £10,000 approximately. Four capstans at the four corners of the lock, the drums of the opening and closing chains of the four pairs of lock gates, and the sluice-gates, are also worked by hydraulic machinery. Another bridge on the same system, but with differences in detail, has been recently completed at St. Malo.

L. V. H.

Automatic Apparatus for Scouring Sewers. By H. Mamy.

(Le Génie Civil, vol. viii. 1886, p. 209, 1 plate and 6 woodcuts.)

The scouring efficiency of water depends upon its volume; it varies inversely with the period of discharge of a given volume, and is proportional to the velocity of discharge in the desired

direction. The velocity is gradually expended in the process of scouring, so that relays of discharges must be provided along a sewer to ensure the removal of the solid sediment. Experiments have proved that, under certain conditions, a discharge of 88 cubic feet of water in thirty seconds would scour a straight length of 820 feet of sewer. Mr. Parenty's scouring apparatus consists of a siphon, one end of which dips into the reservoir from which the supply of water is drawn, and the other end into a movable bucket hanging over the inlet of the discharging-culvert. The bucket is suspended by a chain, passing over a pulley, to whose other extremity a counterpoise weight is fastened, dipping into the reservoir. The weight of the counterpoise, when not immersed, draws up the bucket and closes the siphon. As the water in the reservoir rises, the counterpoise loses weight by immersion in the water, and the bucket, becoming the heavier of the two, descends, causing the water to discharge from the siphon, till the lowering of the water in the reservoir makes the counterpoise draw up the bucket again over the outlet of the siphon. The arm of the siphon in the reservoir must be 1 foot lower than the other arm, to allow for the excess of depression of the water in the reservoir at the end of the flow, owing to the momentum of the current. Any shock of the rising bucket against the siphon may be prevented by making the counterpoise begin to act before the termination of the flow, or by making the counterpoise descend into a well of nearly its own cross-section. The siphon can be filled either by the aid of some form of small auxiliary inverted siphon, as illustrated in the article, or by means of the suction of a water-jet. As the rate of flow depends upon the head of water, it is advantageous for the reservoir to have a large area in proportion to its depth. Drawings are given of an apparatus which can discharge 106 cubic feet of water in twenty-five seconds; and a siphon has been constructed capable of discharging 350 cubic feet in twenty seconds, and having an initial discharge of 28 cubic feet per second. This system has been adopted in several French and Belgian towns.

L. V. H.

An Application of the Erect Siphon for Sewerage purposes.

By — EGER of Breslau.

(Gesundheits-Ingenieur, 1886, p. 184.)

In the execution of drainage-works it often becomes necessary to carry the sewage across canals or watercourses at such levels as to involve either the construction of an inverted siphon under the bed of the stream, or to necessitate the employment of pumps to pass the obstacle. The former plan is the one usually adopted, owing to the saving in working-expenses. It, however, involves very considerable first cost, and in the event of an imperfection or any failure in the pipes, the siphon is extremely difficult to repair.

The Author states that, in carrying out the sewerage of Breslau, it has been necessary to cross the Oder by means of two inverted siphons and one pipe running under pressure. Moreover, a suburb, on an island enclosed by two arms of the river, has been recently connected with the outfall by means of an inverted siphon 30 centimetres (12 inches) in diameter and 90 metres in length, sunk to the bed of the Oder below the Wilhelms bridge. To provide for the cleansing of the siphon, it is necessary to carry a pipe horizontally from the lowest part of the dip to a manhole on one bank of the river. The various precautions to be observed in the construction of such siphons are set forth. Although the above siphon was executed under very favourable conditions, its cost, together with the manholes on either bank, amounted to 15,000 marks (£750). Shortly after the completion of this siphon it became necessary to drain the Sand Island, and to carry the sewage to the outfall system. The area of the island is about 4·5 hectares, with a total population of two thousand persons. To connect this drainage-area with the existing system by means of an inverted siphon under the Oder, would, for various reasons mentioned by the Author, have been both difficult and costly, and he therefore resolved to have recourse to an erect siphon. A bridge, connecting the Sand Island with the right bank of the Oder, was in process of construction, and he decided to attach to the footway-supports of the bridge a cast-iron pipe, 15 centimetres (6 inches) in diameter, in 5-metre lengths, bolted together with india-rubber rings between the flanges. The horizontal pipe across the bridge is connected at either end with vertical arms, dipping into manholes in which the sewer terminates. The lowest point of the sewage system of the island lies at 5 metres above datum on the left bank of the river. A storm-overflow, discharging into the Oder, comes into action as soon as the sewage rises 30 centimetres in the manhole, but it can be used as an outfall, if needs be, by the shifting of a penstock. The part of the manhole below the invert of the sewer is divided by means of a wire screen into two parts, one of which serves to retain the suspended and solid impurities, and into the other the vertical arm of the siphon descends. The level of the roadway of the bridge is 9·12 metres above datum, the level of the horizontal pipe of the siphon is 8·22 metres above datum. The pipe, in all parts where it is exposed, is surrounded with five layers of felt to guard against frost. The level of the invert on the right bank of the Oder is 4·74 metres above datum, giving a fall in the sewer of 0·26 metre from one bank to the other. On this fall, and with a total length of 112 metres, the siphon is estimated to carry away 9 to 10 litres of water per second, which is in excess of the total sewage flow of the island. To provide for a heavy rainfall six storm-overflows have been introduced into the drainage system. On the end of the vertical arm of the siphon a self-acting air-valve has been arranged. A wrought-iron cylinder, 1 metre in height and 0·75 metre in diameter, serves as an air-vessel, and forms the uppermost portion of the

rising arm of the siphon. Both the horizontal and the vertical arms of the siphon lead into the lower part of this cylinder, and in this vessel the air from the whole of the siphon can be collected. On the top of the cylinder a Körting's aspirator has been placed, the suction of which, connected with the interior of the cylinder, is actuated by the town water. The supply-pipe is 3 centimetres in diameter, and the flow of water is regulated by a valve, worked by a counterbalance-weight, which shuts off the supply directly the cylinder is full of water (when, therefore, the whole of the air is exhausted), and re-admits the water to the aspirator as soon as the cylinder becomes nearly full of air. The counterbalance-weight is moved by a float which rises and sinks in accordance with the water-level within the cylinder. The exhaustion of the cylinder usually needs about one or two minutes, during which time about 0·25 cubic metre of air is expelled. This process occurs generally about five or six times in the twenty-four hours. The exhaustion of the whole siphon, when it has been thrown out of working, takes from six to ten minutes. The degree of rarefication fluctuates considerably, but is generally equivalent to about 2½ atmospheres. The siphon has been at work uninterruptedly for several months with satisfactory results. The Author states that this system of working a siphon is capable of many important applications for industrial purposes, and he has secured a patent for it.

G. R. R.

The Röckner-Rothe Process for the Purification of Town Sewage.

(Monatsblatt für öffentliche Gesundheitspflege, 1886, No. 3.)

The whole of the sewage of Essen, which contains the domestic waste-water, the soiled water from manufactories, and the rainfall from the streets and courts, flows into the Bernebach, a small tributary of the Emscher, and the pollution thereby occasioned has been the source of much complaint. So far back as June 1875, the Government ordered that measures should be taken to abate the nuisance. At length, owing to the representations of the authorities of Altenessen, it was decided to carry out a system of treatment in tanks, designed by the borough architect, Herr Wiebe, which should have been in operation by April 1, 1885. Almost at the same time that this plan was resolved upon, the Röckner-Rothe process was made known, and after careful inquiries, the authorities reported that this system had undeniable advantages over the tank treatment, and an apparatus capable of dealing with about one-quarter of the town sewage was put in hand, and was completed by the 30th of July 1885. The volume of liquid to be dealt with at Essen may amount, in wet weather, to 18,000 cubic metres per diem. Since this date the process had been carried on day and night without stoppages of any kind, and has given entire

satisfaction. A complete description of the apparatus is given,[1] and it is stated that the treatment is conducted wholly without smell. The clarified effluent had a yellow tinge, but was quite free from odour. The staff consists of only two men.

Samples were taken in properly sterilized flasks by the deputation who furnished this report on the works of the sewage-water, of the clarified effluent, and of the sludge or deposit, and having been duly sealed with cotton-wool plugs and glass stoppers, these were forthwith transmitted to Brunswick for analysis. The results of these analyses proved that the foul-smelling sewage-water had been converted by the treatment into a clear, colourless, feebly-alkaline liquid, which shows no tendency to putrefy, and which, on exposure to the air, merely becomes slightly turbid in consequence of the separation of carbonate of lime. The dissolved organic substances had, in consequence of the lime-treatment, been converted into stable and innocuous compounds, and rendered capable in a very high degree of resisting putrefactive changes.

The maintenance of this state of things was further secured by the almost total separation of the phosphoric-acid compounds which furnish the food-stuff of micro-organisms. The sulphuretted hydrogen, with the accompanying smell, had quite disappeared, and the amount of combined chlorine was decreased. On the other hand, the harmless nitrates and nitrites were slightly increased in quantity, owing to the oxidation of the ammonia. Nearly all the nitrogen in the suspended organic matters had vanished, and with it about half of the albumenoid ammonia. The biological examination furnished equally remarkable results, inasmuch as, out of 1,134,000 colonies of micro-organisms in 1 cubic centimetre of the sewage-water, only 3 colonies were found in the same volume of the clarified effluent. Other examinations of the sewage and effluent conducted by Dr. Wahl, of Essen, at different dates, when the pollution was greater, showed in the sewage-water 1,686,000 to 5,245,000 colonies per cubic centimetre, and in the clarified effluent 34 to 178 colonies. The sludge, dried at 100° Centigrade, contained 75 per cent. of inorganic, and 25 per cent. of organic substances. In the former was 0·84 per cent. of phosphoric acid, and in the latter 0·708 of nitrogen. The value of the nitrogen and phosphates in 1 cubic metre of the air-dried sludge (containing about 50 per cent. of water), is estimated at 5 marks (5*s.*) The sludgy manure is therefore incapable of being carted to a distance, but should command a sale at a moderate price near the works. According to the Essen authorities, each cubic metre of sewage-water yields about 2·35 litres of sludge, containing 70 per cent. of water. The cost of treatment per cubic metre of sewage-water is given as 1·7 pfennig, or, taking the value of the sludge at 0·8 pfennig, the approximate cost may be set down at 1 pfennig per cubic metre (£2 5*s.* 5*d.* per million gallons). It is estimated, however, that in working on a large scale the cost could be brought

[1] Minutes of Proceedings Inst. C.E. vol. lxxix. p. 412.

down to one-half of this amount. In conclusion, the reporters state that, as no system of chemical treatment will ensure complete purification of fouled water, the results obtained by this process may be considered to be satisfactory, and they recommend that in the town of Brunswick an apparatus shall be constructed, similar to that in Essen, and that the Röckner-Rothe process shall be carried out in a quarter of the town in which water-closets are used.

G. R. R.

The Probable Causes of the Typhus[1] *Epidemic in Zurich in* 1884.

By Dr. Gustav Custer, of Rheinek.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xviii. 1886, p. 142.)

In the town of Zurich, and in the nine communes in immediate connection with the same included under one common administration, an outbreak of typhus occurred, which, during the period from March to July, 1884, caused one thousand six hundred and twenty-one cases of sickness, distributed over the different months as follows: —March, one hundred and six; April, nine hundred and twenty-one; May, three hundred and eight; June, one hundred and fifty-eight; and July, forty-six, after which the number of cases regularly decreased, until in October only thirteen patients were attacked. In the town itself and in the suburbs, which contained a total population of eighty-three thousand souls the cases were thus grouped:—six hundred and twenty-seven cases in Zurich proper; four hundred and seventeen in Aussersihl, the principal suburb; and somewhat irregularly over the remaining parts of the district. The total number of deaths was one hundred and forty-eight, or 9·1 per cent. of those attacked; and, in spite of a somewhat low death-rate, the epidemic gave evidences, in the lingering nature of the illness and in several complications of various kinds, that it was of a severe character.

The causes of the outbreak were carefully considered by a scientific Commission, and the results of their deliberations, more particularly with respect to the water-supply of Zurich, are embodied in a voluminous report to the municipal authorities. This report contains numerous detail-plans, diagrams, and chemical tables connected with the inquiries of the Commission, and furnishes a valuable contribution to the history of this disease. As factors which must be taken into prominent consideration in dealing with this outbreak the Author mentions:—

1. Its sudden and almost explosive character, the rapid increase of the infection, and its relatively speedy decrease.

2. The astonishingly even distribution of cases over the town and suburbs.

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[1] Enteric or typhoid fever.

And 3. The almost entire limitation of the epidemic to the Zurich joint district, together with the total immunity at the same time of the surrounding neighbourhood from attack.

For the elucidation of these marked characteristics no sufficient data were obtainable from a careful examination of the personal, social, and hygienic conditions of the patients. The classes who were least favourably situated were not more attacked by disease than those who were in all respects better off. Nor could the density of the population be proved to have had any influence, as those districts which were sparsely inhabited suffered as severely as those which were most crowded. The inspection of the arrangements for the disposal of the fecal matters in the infected quarters gave the remarkable result that the number of cases in those houses where the sanitary arrangements were of the worst possible kind were not exceptionally large, and indeed that, in comparison with the inhabitants of houses furnished with a tub-system, the dwellers in houses with uncovered porous cesspits, with wooden soil-pipes, had the greater immunity from disease. The main-drainage system consists of three perfectly distinct sets of sewers, and little doubt can exist that, if the spread of the malady was attributable to the entry of sewer-gas into the dwellings, no such equable and symmetrical spread of the infection as really took place was possible from this cause. Apart from this, many cases occurred in houses wholly disconnected from the sewers. A negative result was likewise obtained from a study of the levels of the sub-soil water.

Setting aside, therefore, the above possible sources of infection, there remained only one other means by which the typhus could have been disseminated, namely, the domestic water-supply. This had been often suspected as a probable cause of the outbreak, or at any rate as the principal channel for its diffusion. In order to form an opinion on this point the Author gives a sketch of the means by which the town was supplied. The system was a mixed one, as there were numerous springs, one hundred and sixteen in all, brought in from the surrounding heights, supplying three hundred and seventy-two public and private fountains. There were also four hundred and ninety-three wells, partly used for drinking purposes, and the town supply derived from the lake was laid on to houses having a total population of sixty-four thousand one hundred and forty persons, or 77 per cent. of the inhabitants. The water pumped into the town for domestic use has been growing in favour for drinking purposes, and its employment in this way has largely increased during recent years. The filter-beds were originally calculated to yield 10,000 cubic metres per diem, but in consequence of great want of soundness in the pipes laid in the bed of the river Limmat, leading from the filters to the pumping-station, it was found possible to obtain as much as 21,000 cubic metres daily, as the demand increased. A large proportion of the supply thus consisted of unfiltered Limmat water. So extensively was this impure water in demand for drinking purposes

that it was only possible in the case of 9·6 per cent. of those persons attacked by the disease to demonstrate that they had not partaken of it. Indeed it is stated in the report that in no single instance could it be proved that none of this water had in any way come into the system of the patient. All evidences in fact lead to the conclusion that it was to this cause that the spread of the epidemic must be attributed. Peculiar interest attaches itself, therefore, to the investigations of Professor Klebs of Zurich, who announced that both in the mud from the filter-beds and in the water itself he had discovered the characteristic typhus *bacillus*, with which the researches of Gaffky had made them acquainted. Professor Cramer, however, was of the opinion that the variety of *bacillus* obtained by Klebs differed materially from the true typhus *bacillus*. The details of the controversy respecting the micro-organism in question are considered by the Author at considerable length, the final verdict of Koch being adverse to the assertion of Klebs that he had indeed discovered the typhus germ in the Zurich filter-beds. The result of the recommendations of the Commission is that an entirely new line of cast-iron pipes has been laid from the lake to some new filter-beds, and from thence to the pumping station, at an estimated cost of 2,200,000 francs (£88,000).

G. R. R.

The Micro-membrane Filter of Breyer.

By Dr. H. Buchner, of Munich.

(Gesundheits-Ingenieur, 1886, p. 305.)

The experiments described in this communication were conducted with an ordinary domestic filter, which consists of two tall cylindrical vessels, fitting one within the other, the outer of which is circular, the inner one hexagonal in section. They are made of metal and are nickel-plated. The total height of the filter is 72 centimetres (28·3 inches), and at the bottom of the inner vessel are the two paper leaves which constitute the actual filtering material. These sheets have each of them an area of 230 square centimetres (35·6 square inches). The filtered water collects in the space between the inner and the outer vessels and can be drawn off by means of a tap. As the inventor stated that this filter would retain the living germs of micro-organisms, these tests were designed to investigate its ability to do so. For this purpose four series of experiments were conducted, certain of them being intended to ascertain whether it was capable of holding back the bacilli of typhus and other micro-organisms of specific character.

For the first experiment spring-water rich in the usual germs was employed; for the second, water filled with the bacilli of typhus (or enteric fever), obtained by means of pure cultivation in a meat-juice-peptone-solution; for the third experiment water im-

pregnated with the spores of bacilli, obtained from hay-solution, cultivated in meat-juice; and for the fourth, spring-water containing numerous germs was further tried with new leaves. In all cases the apparatus was first carefully washed in all its parts with sterilized water, before beginning the experiments. The results obtained by gelatine-cultivation are tabulated beneath; in each case the mean of three observations has been taken:—

Nature of Sample.	Quality of Water.	Average Number of Colonies in 1 cubic centimetre of the Water.	Maximum and Minimum Number of Colonies.
I. Spring-water rich in germs	Unfiltered . Filtered .	1,400 0	1,500 & 1,300 1 „ 0
II. Water impregnated with typhus-bacilli . . .	Unfiltered . Filtered .	190,000 100	222,000 & 160,000 146 „ 22
III. Water impregnated with hay bacillus spores. .	Unfiltered . Filtered .	44,000 119	48,000 & 40,000 150 „ 103
IV. Spring-water rich in germs. New filtor-leaves . .	Unfiltered . Filtered .	4,830 17	5,500 & 4,000 20 „ 15

These experiments prove that a sample of spring-water, rich in micro-organisms, can be almost wholly freed from them by the use of this filter. With the bacilli of typhus the success was so far complete that only one germ in every nineteen hundred passed through the pores of the filtering material, and it must be remembered, that water, so strongly infected as was this sample, could never be encountered in practice. The results in the case of the hay-bacilli were not relatively so good, as about five times as many spores passed the filter as in the case of the typhus-bacilli. The results with the new sheets were not quite equal to those obtained in the first instance, and may have been due to the imperfection of the joints in the metal frame-work, or to some minute flaw in the leaves. Experiments were also made with clay-water to test the power of the filter to remove mineral matters in suspension. Clay was beaten up in water until tho liquid was so turbid that it was impossible to see the cross-bars of a window through a stratum 10 centimetres in thickness. As will be apparent from the previous tests, the filtered water was in this case absolutely clear, but the yield was rapidly reduced in volume. Accordingly, as a test of endurance, 100 litres were passed through; the time taken to pass each 20 litres being noted. It took eight hours to filter 100 litres, the mean speed per litre being 4·8 minutes; varying from 2·3 minutes per litre for the first 20 litres, to 8·7 minutes for the last 20.

The general result of the experiments is very favourable: in its power of extracting minute organisms this filter is certainly surpassed by no other with an equally rapid delivery, for the yield with fairly pure liquids amounts to 500 cubic centimetres per minute,

(1 gallon in nine minutes) or 100 litres in three hours twenty minutes, with an average head of 50 centimetres. When used with very muddy water the filtering material would probably require renewal after passing 100 litres, but the cost of new sheets is only 20 pfennige (*2d.*). The Author points out that in a filter of this nature there is little danger of the actual pollution of the water during its passage through the filter, in consequence of the growth of micro-organisms in the pores of the filtering material, which may often happen in filters of the ordinary construction; and moreover as the leaves, when wetted, are of the consistency of moistened blotting-paper, they can, when they are done with, say after six weeks' or two months' use, be crumpled into a ball and thrown into the fire.

G. R. R.

The action of Water upon Metal Pipes and the injurious effects of Lead Pipes upon Water.

(Gesundheits-Ingenieur, 1886, p. 314.)

Widely different opinions have been published on these subjects by experts, and even the official regulations with reference to the employment of various kinds of water-pipes are greatly at variance. Thus, in Germany, Switzerland, and in other places, galvanized iron piping is used without hesitation, while by Government decree, the use of pipes of this kind is forbidden in Austria, and in one instance their employment in Saxony was objected to. Some recent investigations of Mr. Lory of Grenoble have shown that water containing organic matter in solution attacks iron pipes very speedily, and after many analyses of water conveyed to Grenoble from different sources in iron pipes, and also of water known to have attacked pipes and led to the formation of scabs or carbuncles of oxide of iron in other places, Mr. Lory had invariably found that the scabs—consisting mainly of hydrated oxide of iron—contained from 5 to 10 per cent. of organic matter. He has been led, therefore, to conclude that the destructive action upon such pipes is due in the first instance to substances of organic origin. This may, to some extent, explain the reason why in some places cast-iron pipes remain quite free from corrosion, whereas, in other cases, even after six months, as happened at Grenoble, they became covered with rust-carbuncles. The influence of soft water on lead pipes is considered, in the light of a recent report of Dr. White, Medical Officer of Health of Sheffield, and some experiments, conducted last year at the Hygienic Institute of Pesth, are quoted, in which the water passing through a pipe 39 metres in length, was found to contain from 0·085 to 4·7 milligrams per litre of lead; the latter high percentage only occurred, it is true, after the water had remained in contact with the lead for one

month. In view of the destructive action of some kinds of water on cast-iron pipes, information is sought concerning the protection afforded by covering the pipes internally with a coating of magnetic oxide, and the results of any experiments bearing upon this question.

G. R. R.

Apparatus for Moistening the Atmosphere of Mines, to prevent Coal-Dust Explosions. By L. PARENT.

(Le Génie Civil, vol. viii. 1886, p. 296, 4 woodcuts.)

Hitherto no attention has been paid to the hygrometric condition of the air in mines; but now that coal-dust explosions have become more frequent, it is admitted that the moisture removed by the drier and colder air entering from outside, and issuing charged with humidity, must be restored. It is accordingly proposed, by means of spray-producers, to supersaturate the current of air at its entrance into the mine, so that the air may yield up the moisture which it carries along in mechanical suspension in the interior of the workings, and issue in a state of saturation. Moreover, by furnishing an ample supply of water in a fine state of division at suitable places, it would be possible to convert the coal-dust, in suspension in the headings and shafts, into liquid mud. The spray-producer illustrated and described is simple and strong, and has afforded satisfactory results; it has the shape of a lyre, and consists of two curved pipes terminated by two nozzles facing each other. A jet of water under pressure issues from each nozzle; and these jets meeting in the small intervening interval, which should not exceed from 0·4 to 0·8 of an inch, are converted into spray. Water under pressure is readily obtained in underground mines, and the arrangement described would secure mines against coal-dust explosions.

L. V. H.

The Causes of Explosions in Lamp-Black Furnaces. By Professor ENGLER, Carlsruhe.

(Journal für Gas Beluchtung, &c., 1886, p. 147.)

In a communication from the Author to the above Journal in 1885 (p. 830), he stated his opinion that only such substances as naphthalene, powdered resin, &c., producing combustible gases when heated, could develop or propagate explosions, and that other substances, such as soot, powdered charcoal, &c., combined with air, formed neither a flame, nor an explosive mixture. From this it is to be inferred that, in all probability, finely-divided soot cannot be the cause of the frequent explosions in lamp-black

furnaces. The Author now gives the following details of further experiments:—

The Lamp-Black manufacture in the Black Forest of Baden is carried on in five works, having a weekly production of about 2½ to 3 tons of lamp-black. The material formerly used was the local firwood; but latterly the residues of such wood, after distilling and pressing, have been employed, which consist of about equal parts of heart-wood and bark. Of late years, in addition to these, a considerable quantity of coal-tar, and the heavy residues from the distillation of the same, have also been employed. Each furnace consists of two slightly inclined ovens into which the material is thrown, or for tar, oil, &c., two crucibles are placed over the ovens and supplied by pipes. The gases, carrying the lamp-black, pass first into a brick cooling-chamber, and then into a tower, divided into two compartments by a vertical wall, from which they pass into a chimney. A coarse cloth fixed in one division of the tower retains the last portions of the lamp-black. The firing is commenced every Tuesday and continued till Saturday, the ovens being allowed to cool on Sunday, and emptied on Monday in each week.

One hundred parts of tar yield twenty-five parts of lamp-black, and one hundred parts of wood-refuse twenty parts. Analyses of the gases in the cooling-chamber about 3 feet from the point of combustion give the following results:—

Carbonic acid	6·2	to	10·8	per cent.
Carbonic oxide	0·5	„	1·4	„
Oxygen	6·2	„	13·4	„

Marsh-gas, or hydrogen, were not found in appreciable quantities. From this it appears that the gases developed with the lamp-black by the imperfect combustion of the various raw materials, contain only very small proportions of hydrogen and carbonic oxide, and it is impossible that with ordinary working the explosions in question can arise from the mixture of these gases. Lamp-black also does not explode with air, so that there only remains the possibility of a simultaneous admixture of particles of lamp-black and combustible gases and air.

In the former communication it was shown that lamp-black or powdered charcoal may cause explosions with air containing 2·5 per cent. of marsh gas, or 3·5 per cent. of coal-gas; while, in the absence of the lamp-black, explosions occur only with 5·6 per cent. of marsh-gas, or about 8 per cent. of coal-gas. As more than double the latter quantity of carbonic oxide is necessary to produce explosive mixtures with air, it may be safely assumed that considerably more than the maximum of carbonic oxide found (1·4 per cent.) is required to cause an explosion; and it is evident that such explosions cannot occur in the ordinary working of the ovens. Experience shows that they occur chiefly during the firing up of the furnaces, and also during the working, if too large quantities of tar, oil, or other materials are suddenly let in. In the first case

explosions may arise from putting the fuel on the still hot bed of the furnace, thus forming gases which explode when mixed with air in the cooling-chamber in contact with the flames entering therein. In the latter case the explosion may be due to similar unburnt gases, as, even with a constant flame in the furnace, if too much tar is run in, the supply of air may be deficient for the combustion of all the gases generated; these then mix with the air in the cooling-chamber, or with lamp-black and air, and produce the necessary conditions for an explosion. The best means for avoiding such explosions appear to be careful working, and above all to set fire to the materials directly they are introduced into the furnace, as well as to carefully regulate the supply of the material while working.

C. G.

A New Method of determining the Specific Gravity of Gases.

By F. Lux.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xxx. 1886, p. 503.)

This method depends upon the well-known Archimedian principle, and is specially intended for use in gasworks, the apparatus being continuous in action, and giving the specific gravity by inspection. A cylindrical glass vessel, about 12 centimetres wide, and 70 centimetres high, closed at the top with a ground-glass stopper, has two tubular apertures opposite to each other near the top, closing by cocks. These, when opened, and connected with the source of supply, allow the vessel to fill with gas, but to ensure perfect distribution the tube on the admission-side is prolonged downwards through about half the depth of vessel, or to the level of the water with which it is about half filled. The measuring instrument resembles an ordinary areometer or hydrometer, having a loaded spherical float with a divided vertical stem; but in addition it has a glass bulb at the top of the stem in the gas space. The stem joining the two bulbs is 4 millimetres broad and 1 millimetre thick, or has a section of 0·04 square centimetre; the capacity of the hollow glass bulb is about 300 square centimetres. As the weight of a litre of air is in round numbers 1·38 gram, the difference in the weight of the bulb in air and in vacuo will be about 0·4 gram, corresponding to 0·4 cubic centimetre of water. If the line of flotation in air is marked on the stem, and then the air in the upper space of the vessel is exhausted, the hydrostatic equilibrium will be disturbed, and the float will sink until 0·4 cubic centimetre of water is displaced by the immersion of the stem to a depth of 10 centimetres, which, when marked, gives the line of flotation for gas of specific gravity 0. The interval between the marks when divided into single millimetres gives a scale of 100 equal parts, whereby the specific gravity of any gas lighter

than air is indicated to within ½ to 1 per cent. of the truth, which is sufficiently accurate for practical purposes.

The actual determination of the zero-point of the scale is made, not by flotation in a vacuum, but by filling the gas space with hydrogen (specific gravity 0·07), which can be easily obtained of sufficient purity for the purpose. The space between the two marks is then divided into ninety-three parts instead of one hundred, and the scale is prolonged by adding seven of these divisions at the top, and a similar continuation below the 100-millimetres level gives the scale for gases heavier than air. A thermometer passing through the stopper gives the temperature in the gas space, and another at the bottom that of the fluid, in order to admit of the necessary corrections for change of volume by irregular heating being made.

A further important application of the apparatus may, according to the Author, be made in gas analysis, which, as at present conducted, consists essentially in alternate measurement of volume and removal of components by absorptive media; instead of which the composition of a gas mixture may be determined by taking the specific gravity of the individual components. For this purpose, supposing the mixture contains a gases, $a - 1$ specific gravity instruments will be required, which must be arranged in series alternately with the absorption vessels. From the observed specific gravity the composition of the gas may then be easily calculated. Supposing the specific gravity of a mixture of two gases to be indicated by s_3, that of one component (x) by s_1, and that of the other component $(1 - x)$ by s_2, the relation of these quantities will be—

$$s_3 = x \cdot s_1 + (1 - x)\, s_2 \qquad \text{or } x = \frac{s_3 - s_2}{s_1 - s_2}.$$

If the absorption vessels be made sufficiently large, and the absorbing media kept active by renewal from time to time, it will be possible to analyse a gas by a single series of simultaneous observations of the specific-gravity instruments.

H. B.

Volumetric Regulator for Ventilating-Fans.

By L. Desailly, Engineer to the Liévin Colliery (Pas de Calais).

(Bulletin de la Société de l'Industrie Minérale, vol. xiv. 1885, p. 1073.)

As the useful effect of an exhaust ventilating-fan running at a given speed is not constant, but is liable to interference from variations in the resistance to the flow of air through the workings of the mine (which may be caused by falls of roof, accumulations of coal, opening or closing of temporary air-ways, differences of underground and surface temperature, &c.), it is desirable that the speed of the fan itself shall be so controlled

that the final velocity of the air passing through an airway of fixed and unvarying dimensions, after it has circulated through the mine, shall be uniform, however much the reduction of pressure below that of the atmosphere may vary.

This velocity may of course be gauged by an anemometer of any ordinary construction, but for controlling the governor about to be described it is preferred to employ a disk of suitable area suspended pendulum-wise from an axis, on which is fixed a lever free to move within certain limits (defined by a quadrant constructed of some insulating material) and connected to a small cataract to prevent over-sensitiveness. At the centre and at each end of the quadrant are insulated plates communicating with a small galvanic battery, and with two electro-magnets which control the governor-gear of the engine. The finger end of the lever is fitted with a metallic brush, and is so arranged that when it is in its central position both the magnets are disconnected from the battery, but in its upper or lower position one or other of them will be connected.

On the throttle-valve of the engine, or on the cut-off gear, which may conveniently be of the Meyer or some similar type, is a ratchet-wheel and lever, the latter receiving a slight to-and-fro motion from some reciprocating part of the engine. This lever carries two pawls acting in opposite directions, so arranged as to fall out of gear by their own weight, unless acted on by one or other of the electro-magnets before mentioned. It will be evident that, so long as the current of air through the mine maintains its normal speed, this ratchet arrangement will remain inoperative, but that any increase or decrease of air-current will complete the circuit with one or other of the electro-magnets, and cause the throttle-valve spindle (or the variable cut-off gear, as the case may be) to be screwed down or up until the normal speed of air is restored. By a simple contrivance the magnets are disconnected when the extreme travel of the gear in either direction is reached.

The current-meter or anemometer may of course be at any distance from the engine and governor, and the only part of the apparatus requiring maintenance is the battery for charging the electro-magnets.

The Paper is illustrated by engravings illustrating the apparatus as applied to a valve-gear with variable cut-off.

W. S. H.

On the Structure of Blast-Furnace Fuels. By W. Thörner.

(Stahl und Eisen, vol. vi. 1886, p. 71.)

In former communications the Author called attention to the importance of porosity in coke and charcoal as affecting their use as fuel in the blast-furnace, and described a simple and exact

method of determining it by means of a volumometer. He now publishes the result of a great number of investigations made upon different samples of coke, charcoal and coal, which are given in the Table (p. 479). Microscopic sections have also been prepared by grinding and polishing these slices in the manner originally described by Sorby for the study of rocks, and photographs of these, taken by electric light, are given in illustration. The chief differences in these are in the relative sizes of the hollow spaces, and the thickness of their walls, the cavities being fewest in number, largest, and with the most massive walls in gas-retort coke, while in coke from Silesia, burnt in clamps, the hollows, though much smaller, are more numerous and closer together, in which respect they approximate to wood charcoal. There is, however, this difference, that in charcoal the cavities are essentially tubes showing a linear arrangement in a longitudinal section, while in coke they are more or less spheroidal and isolated.

The resistance to crushing has been determined by subjecting weighed quantities (100 grams for coke or 50 for charcoal) in pieces of 10 millimetres to the action of a plunger in a cylinder 55 millimetres in diameter. A millimetre scale is cut on one side of the plunger, and the depression produced by loading it at the top is a measure of the crushing force employed. It was found that the greatest crushing effect was produced by the weight first applied, and therefore the experimental loading was not continued beyond 2 tons on the plunger, which corresponded to 0·9 kilogram per square millimetre on the surface of the material. The results show that the porosity and strength are intimately related in coke and charcoal, the more porous gas-coke crushing easier than the denser kinds made for blast-furnace use. The weakest charcoal is, as might be expected, that from pine-wood, birch coming next. Beech-wood charcoal is, however, stronger than that made from oak, although the latter contains fewer pores in the mass than the former.

In the next series of experiments a weighed quantity of fuel broken to the size of a lentil was exposed at a white heat to a stream of hydrogen for an hour, which caused a loss of weight varying from 0·25 to nearly 30 per cent., which the Author attributes to hydrocarbons enclosed in the hollow spaces. The result shows that those fuels which have the highest reducing effect in the blast-furnace, namely, charcoal, and coke burnt in open piles, give the largest proportion of these gases, whether they be enclosed hydrocarbons or decomposition products.

The experiments on the oxidizing-power of carbonic acid and air at high temperatures were made in a porcelain tube, which occupied the position of the muffle in a gas-furnace, formerly used as a muffle-furnace. The interior of the furnace-space above the tube was filled with lumps of firebrick, and heat was applied by five large Bunsen burners below the tube. About one hour and a half is required to bring the tube up to a bright white heat, which can then be steadily maintained throughout the experiment. Care

No.	Character and origin of Fuel.	Ash.	Specific gravity. Apparent.	Specific gravity. Real.	Porosity. 100 grams contains Pores.	Porosity. 100 grams contains Solid.	Loss of volume under 2 tons crushing weight.	Hydrocarbons inclosed.	Loss in CO_2 in thirty minutes.	Loss in air-current in ten minutes.
		Per cent.	Powder.	Mass.	Cub. centimetres.	Cub. centimetres.	Per cent.	Per cent.	Per cent.	Per cent.
1.	Retort coke, Pluto Mine	3·8	1·825	0·858	61·6	54·8	54·7	..	10·6	46·8
2.	" Fried-d. gr. "	7·5	1·811	0·868	60·6	55·2	51·5	0·25	11·8	45·0
3.	Pressed coke, Coln Müsen Co. . .	7·7	1·852	0·984	47·6	54·0	47·6	1·40	13·8	51·0
4.	" " " " . . .	6·9	1·786	0·969	47·2	56·0	51·9	1·15	8·4	48·9
5.	Coppée oven coke " " . . .	8·0	1·880	0·926	54·8	53·2	48·6	1·13	8·7	50·1
6.	Carlsglück and Blandenfeld coke .	7·8	1·825	0·909	55·2	54·8	47·5	1·55	8·3	54·4
7.	Maassener deep coal coke . . .	7·3	1·852	0·890	58·4	54·0	50·9	1·70	8·0	51·5
8.	Westhausen-Bodelschwing coke . .	10·6	1·852	0·919	54·8	54·0	48·5	..	9·5	52·9
9.	New Iserlohn-Langendreer " . .	8·8	1·852	0·874	60·4	54·0	52·4	..	12·2	46·8
10.	Tannenbaum-Bochum " . .	8·45	1·894	0·890	59·6	52·8	51·9	0·75	6·8	57·1
11.	Germaniahütte Grevenbrück " . .	7·6	1·909	0·903	58·4	52·4	53·4	..	8·9	52·1
12.	Heinrichshütte Company's " . .	7·6	1·887	0·980	49·0	53·0	46·7	..	6·9	52·5
13.	Silesian clamp burnt coke . . .	2·9	1·488	1·046	28·4	67·2	43·1	29·7	45·6	87·7
14.	Pine charcoal	2·9	1·626	0·382	200·4	61·6	72·7	17·9	96·3	100·0
15.	Oak "	2·45	1·347	0·587	96·2	74·2	58·7	13·2	85·0	78·6
16.	Beech "	2·10	1·481	0·594	100·8	67·6	57·8	11·8	95·0	80·3
17.	Birch "	1·65	1·351	0·484	132·5	74·0	60·0	13·2	95·0	100·0
18.	Piesberg anthracite	9·8	1·666	1·572	3·6	60·0	..	..	..	45·4
19.	Borgloh coal	8·3	1·323	1·300	1·4	75·6	..	..	..	74·4

was taken that the current of gas should be perfectly uniform both as regards quantity and pressure.

In carbonic acid the densest oven-coke lost in weight from 8 to 10 per cent. in the first half hour, and a total of 24 to 38 per cent. in two and a half hours, the proportional effect being greatest in the earlier period, owing to the large amount of surface presented to the action of the gas. Clamp coke lost 45·6 per cent. in the first half hour, and was almost entirely consumed in two hours. Charcoal lost from 49 to 68 per cent. in fifteen minutes, and was entirely consumed in half an hour. The average composition of the mixed gas obtained by the action of carbonic acid was in per cent. by volume—

From	CO_2.	CO.	N and Hydrocarbons.
Pine charcoal	17	77	6
Oak ,,	21	74	5
Beech ,,	25	70	5
Birch ,,	20	74	6
Clamp coke	35	61	4
Oven coke	70–80	20–26	4

The oxidizing effect of air being much greater than that of carbonic acid, the experiments were only continued for ten minutes, which was sufficient to consume almost all the samples of charcoal, and from 45 to 57 per cent. of those of coke. The average composition of the resulting gas was 10 to 17 per cent. carbonic acid, 0·2 to 9·3 per cent. oxygen, and traces up to 3 per cent. at most of carbonic oxide.

The Author concludes from his experiments that the theoretical calculations of Belani and Kütscher, published in the previous volume of the same Journal (1885, pp. 603, 794), are justified, and that the future ideal of the coke-manufacturer should be to produce a porous, bulky article as similar as possible to wood charcoal in structure, and that it is only with such a material that an economy of fuel in the blast-furnace comparable to that of charcoal is likely to be realized when using coke.

H. B.

On the Porosity of Iron and Steel. By W. Thörner.

(Stahl und Eisen, vol. vi. 1886, p. 166.)

That iron even when apparently compact is to some extent porous has been known for a considerable time, and the gases condensed in the pores have been extracted and elaborately investigated; but no simple and accurate method of determining the porosity has hitherto been available. The Author has made several experiments in this direction with the volumometer previously used in the determination of the real and apparent densities of charcoal and coke (Stahl u. Eisen, 1884, p. 592), the results of which are recorded below. The method of observing was similar to that

previously recorded, but the work requires to be most exactly and accurately done, as the presence of even the smallest quantity of a foreign substance such as scale, or oxide, paper, or fibre, in the finely-divided metal (fine iron filings) renders the result completely useless. The volumometer used must admit of rapid and accurate reading, and it is of importance to maintain it at the constant temperature of 15° Centigrade while observing.

For the determination of the volume of the porous iron accurately-turned cylinders of 10 millimetres in diameter and 100 millimetres long were used. The displacement was measured in a tube of 12-millimetres diameter, divided to $\frac{1}{10}$ of a cubic centimetre. As glass vessels are easily broken in case of such a heavy mass of metal slipping down while in process of lowering, a cistern of sheet zinc was used in connection with the measuring-tube instead of a glass one. The volumometer used for determining the density of the iron free from pores (*i.e.*, finely-divided) was only 10 millimetres in diameter, and could be accurately read to $\frac{1}{10}$ of a cubic centimetre. The iron was prepared in the Author's Analytical and Microscopic Institute at Osnabrück, by carefully filing the metal after freeing the surface from the adherent scale and oxide. The filings were received upon glazed paper, and then twice gone over with a weak magnet to remove any extraneous impurity. Alcohol was used as the covering fluid. The weight of the turned-cylinders varied from 100 to 150 grams, and from 30 to 40 grams of filings were used as a minimum on each determination. The tensile-strength of the metals experimented upon was also determined upon cylindrical test-pieces 20 millimetres in diameter, and 200 millimetres long.

No.	Porosity of Volume per cent. of Mass.	Specific Gravity of		Volume per Kilogram of		Volume of 1 Kilogram.	Tensile Strength.	Contraction.	Extension.
		Filings.	Cylinder.	Pores.	Metal.				
				Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Kilogs. per mm.	Per cent.	Per cent.
1	1·41	7·142	7·042	2·00	140·00	142·00	..	..	..
2	1·15	7·812	7·722	1·50	128·00	129·50	54·5	53·8	15·0
3	1·95	7·968	7·813	2·50	125·50	128·00	46·1	59·0	27·0
4	0·57	7·784	7·737	0·73	128·28	129·01	62·5	53·0	22·9
5	0·97	7·983	7·908	1·23	125·23	126·46	78·0	38·5	18·0
6	1·22	7·752	7·700	1·58	128·42	130·00	56·5	45·3	15·0
7	1·20	7·921	7·826	1·53	126·24	127·77	57·4	58·3	25·0
8	0·41	7·755	7·729	0·53	128·95	129·48	56·5	52·0	20·0
9	0·97	7·871	7·790	1·25	127·05	128·30	56·5	53·5	19·0
10	2·17	7·931	7·751	2·80	126·10	128·90	56·3	52·3	24·5

No. 1 was ordinary cast-iron, showing numerous cavities filled with cinder upon an etched surface, which accounts for the low observed density. Nos. 2, 4, 5, 7, 8, and 9 were different kinds of Bessemer steel, No. 4 being taken from a locomotive tire-ingot, No. 5 from one intended for making hard forgings, and the

remainder from rail-ingots, Nos. 8 and 9 forming part of the same blow. No. 3 is described as basic ingot iron, and Nos. 6 and 10 as basic steel. From these results it is evident that the porosity of iron and steel is perfectly measurable, and that it is subject to considerable variation in the different kinds of steel. Although strength and porosity are generally in direct relation to each other, the stronger metal being as a rule the denser, several notable exceptions have been observed. These the Author attributes to the irregular distribution of the pores through the mass, and to the impossibility of determining the mean tensile-strength of the ingots of one whole charge from a single test-piece. He also points out that the pores in question are all of microscopic fineness, and must not be compared with visible blow-holes.

H. B.

Mechanical Haulage at the Ironstone Mines of Bilbao.

By — MALLIZARD-TAZA.

(Bulletin de la Société de l'Industrie Minérale, vol. xiv. 1885, p. 1065.)

The ironstone beds of Somorrostro are situated on the summits of a steep chain of hills, some 650 to 1,000 feet high, situated between Bilbao and the sea. At their foot runs the river Nervion, navigable for vessels of considerable tonnage, and flowing into the sea at Portugalete, a few miles away. From the foot of the hills to the loading-jetties transport is effected by railways, usually straight, and with no serious gradients. For the descent of the hill-sides wire ropeways, either on the Bleichert system with two ropes, one for carrying, the other for traction, or on the Hodgson system, with a single rope travelling with the tubs, are in some cases used, but these are only capable of dealing with comparatively small quantities of material. The (Lancashire) "endless chain" system is not suitable, as the gradients are almost always in the same direction and not undulating.

For the transport of larger quantities, self-acting jigs or inclines are used, of which the following may be taken as typical examples:—

The Mac Lean inclined plane is about 330 yards long, with a gradient of 1 in 2. The full and the empty wagons are attached to either end of a single rope passing round two horizontal pulleys at the head of the incline, and controlled by a brake. The useful load for each trip is about 6 tons, contained in two wagons.

The Orconera plane is about 1,300 yards long, with an average gradient of 1 in 7. It has two parallel lines of rail, and about one-half the length is on a curve, necessitating inclined guide-sheaves for the ropes, which are coiled in reverse directions on two drums, about 16 feet 6 inches diameter, keyed on the same

axle. Each drum is furnished with two brake-sheaves, the whole controlled by four strap-brakes shod with cast-iron brake-blocks, and operated simultaneously by the brakesman. A train consists of seven or eight 4-ton wagons, or a net load of from 30 to 32 tons, and about 2,000 tons of ore per day can be dealt with.

The Cadegal plane is about 660 yards long, with a total fall of about 175 yards, the gradients varying from 1 in 2·9, 1 in 3·3, and 1 in 4, on the upper, middle, and lower sections respectively. It is laid with a double track of 3 feet $3\frac{3}{8}$ inches gauge. The drums, about 16 feet 6 inches in diameter, are of slightly conical outline, and are formed of wrought-iron plates $\frac{3}{4}$ inch thick, carried on three cast-iron frames, the two outer ones being formed to receive brake-straps, while the centre one is cogged, and gears into a pinion in the ratio of 8 to 1. The shaft of this pinion carries a large "fly," with four straight wings, about 6 feet 6 inches wide, and 16 feet 6 inches outside diameter, formed of wooden planks on iron frames. By adding or removing one or more planks the speed can be regulated to a nicety, and with 90 revolutions per minute of the fly a train-speed of 200 yards per minute is permitted and never exceeded. The run of 660 yards takes about three and a half minutes, and, as six or seven minutes are occupied in making up the trains at each end, they can be despatched at intervals of ten minutes. A train consists of eight 2-ton wagons, so that about 1,000 tons can be dealt with in a day of ten hours, and by increasing the number of wagons in each train this might easily be brought up to 1,500 tons.

The ropes are of steel, $1\frac{1}{2}$ inch in diameter. The drums are mounted at a sufficient height above the rails to allow the wagons to pass beneath them, and by means of two short inclines in opposite directions, between the drums and the head of the plane, the trains are made up with a minimum of labour.

The Paper is illustrated with drawings and sections of the Cadegal incline and machinery.

W. S. H.

On the Sublimation of Sulphur and Mercury at Ordinary Temperatures. By MARCELLUS BERTHELOT.

(Annales de Chimie et de Physique, 1886, p. 571.)

In the drying-stoves of gunpowder-mills, where powder for military use is exposed to a carefully regulated heat not exceeding 60° to 65° Centigrade, it gives off a peculiar odour recalling that of sulphurous acid. The Author, considering that this might be due either to incipient oxidation or even to the possible formation of a low oxide of sulphur, has investigated the sublimate which is formed at the same time, by collecting it upon plates of glass placed at some distance above the mass of powder.

The composition of this is as follows:—

Sulphur	97·84
Nitre	0·90
Charcoal and other substances not determined	1·26

It is therefore not an oxide but pure sulphur that sublimes at 60°, mixed with a small quantity of the fixed ingredients of the powder which are carried over mechanically. The smell observed is like that of roll sulphur when slightly heated by friction. The sublimed sulphur is entirely soluble in bisulphide of carbon.

This property of subliming at low temperatures explains an observation communicated to the Author by Mr. Mermet, namely, that in England vines in hot-houses are sometimes protected from oidium by scattering flowers of sulphur upon the heating-pipes. The composition of the vapours has, however, not been determined. If the temperature does not exceed 60° or 80° it is likely that the action is much the same as in the powder-drying stores, and that sulphur vapour may be the active agent, and not sulphurous acid.

As this slow sublimation is effected at a temperature 380° below the boiling-point of sulphur, which is 443° under normal atmospheric pressure, the corresponding vapour-tension is practically inappreciable. At 15° or thereabouts the tension must be nil, as no deposit of sublimed sulphur has ever been observed on the glass of cases or tubes in which specimens of crystallized sulphur are preserved in mineralogical collections, except possibly in parts exposed to the direct heating effect of the sun's rays. The sharpness and permanence of the angles of the crystals in collections also speaks against the possibility of such a sublimation.

The following analogous observation has been made upon the vaporization of mercury at ordinary temperatures. The fact is well known, and the tension of mercury vapour has been calculated according to Regnault's formula as 0·0268 millimetre at 20° Centigrade. Now many physicists hold that the vapours of substances by such very feeble tensions have no longer the same infinite diffusibility as those of higher tension, and that consequently their atmosphere is limited. This, however, is not borne out by the observations following, which seem to show that mercury vapour is indefinitely diffusible at the ordinary temperature. In a laboratory where a large mercurial trough is in use, a closely-stoppered bottle of iodine was kept on a shelf in a glazed cupboard 2 metres above the ground, and 2½ metres distant from the mercury trough. There was neither mercury, ammonia, nor volatile acids in the cupboard, which was opened from time to time. After standing several years, the Author observed a ring of red iodide of mercury formed about the neck of the bottle at its junction with the stopper, and similar observations were made in two other rooms of the laboratory. It appears, therefore, that the mercury vapour had slowly diffused through the entire atmosphere of the room, until it reached the bottle of iodine, where a slow formation of iodide resulted, which only became visible after having gradually accu-

mulated for a long period of time. Another result is that chemists working in rooms containing mercurial troughs, as, for example, at the College de France, are continually breathing a mercurialized atmosphere, although no doubt an exceedingly weak one. It does not appear that any injurious effects have ever manifested themselves from such an exposure.

H. B.

A New Chromometric Method of determining Sulphur in Iron.

By J. Wiborgh.

(Jernkontoret's Annaler, 1886, p. 105.)

This process is based upon a similar principle to that of Eggertz, namely, the discoloration of a metal or metallic salt by the formation of its sulphide when it is exposed to the gases evolved during the solution of the iron under examination in dilute sulphuric or hydrochloric acid. Eggertz's method, however, which depends upon the colour due to interference formed by their films of sulphide upon a polished silver plate, is only applicable to the determination of small quantities of sulphur; while the new process is intended for use with all kinds of cast-iron as well as those with only a minimum of sulphur, like the charcoal-smelted forge pig-metal of Sweden.

The apparatus consists of a round-bottomed flask, 3½ inches in diameter, supported by a ring in a sand-bath, heated by a spirit lamp, and closed by an india-rubber stopper with two perforations. Through one of these the funnel tube for the introduction of the acid, which has an india-rubber collar and regulating clamp upon it, passes; and through the other an upright tube, about 10 inches long, cylindrical at the upper end, and about 2½ inches in diameter, where it is turned over into a flange. The lower end is drawn to a narrow tube, which is flush with the under surface of the india-rubber stopper of the flask. The testing material is a circular disk of cotton cloth soaked in a solution of 5 grams of acetate of cadmium in 100 cubic centimetres of distilled water, which when dried is held round the edge between india-rubber rings, and placed over the top of the tube, where it is clamped to the flange by spring clamps, so that all the volatile products of the flask must pass through the cloth before reaching the atmosphere. The iron to be examined is, where possible, reduced to a fine state of division by boring, filing, or pulverizing, and the sample (of a maximum weight of 0·8 gram) is placed in a small test-tube suspended at the end of a stout platinum wire, about 5 inches long, and lowered into the flask, which is about half filled with distilled water and heated to boiling. The wire rests against the neck of the flask, and keeps the tube from upsetting, and so prevents the iron from heaping together on the bottom, where it might be removed from the influence of the acid before being

completely dissolved. The boiling is continued for eight or ten minutes, in order to get the test-cloth properly moistened by the steam. The funnel of the acid tube is filled with sulphuric acid diluted with three times its volume of water, which is carefully admitted at intervals by means of the regulating clamp. About 10 cubic centimetres of the dilute acid are required for 0·4 gram of iron. Any sulphuretted hydrogen contained in the gases evolved is absorbed by the cloth, which becomes more or less coloured on the under side from the formation of sulphide of cadmium, which is of a brilliant orange-yellow when dried. When the iron is completely dissolved, the contents of the flask are kept boiling for eight or ten minutes to drive out the last traces of gas, when it is allowed to cool; and the disk of cloth when removed is dried, and the colour is compared with a standard series previously prepared. The chief point of importance is to maintain a regular flow of steam during the entire operation, which must, however, be so moderated that no distension of the cloth is produced, as in that case the mesh of the fabric will be altered, and apertures will be produced through which the gases may escape without giving up their sulphur contents. It is also of importance that the air in the flask should be previously expelled, so that no part of the sulphuretted hydrogen may be oxidized.

The operation lasts from one-half to three-quarters of an hour, according to the greater or less degree of solubility of the iron under examination.

The scale of colour is formed by operating upon particular weights of iron in which the sulphur has been previously determined by the ordinary analytical method, the yellow-stained disks when dried being preserved for reference. They are seven in number, varying from a very pale buff to a strong primrose or sulphur-yellow tint, to produce any one of which varying weights of iron must be taken according to the amount of sulphur contained. The relations of these quantities for the extremities of the scale are as follow, No. 1 being the palest, and No. 7 the deepest tint:—

Weight of sample		0·80	0·40	0·20	0·10	0·08	0·04	0·02	gram.
Sulphur .	No. 1	0·05	0·10	0·20	0·40	0·50	1·00	2·00	per cent.
	No. 7	0·025	0·05	0·01	0·02	0·25	0·05	0·10	„

The test-cloth when prepared with acetate of cadmium seems to be very stable, having been preserved for several months without change. The colours are brighter than those obtained with other salts: thus the nitrate gives a sulphide of a deep tone inclining to orange, while that from the sulphate is pale and of a yellowish brown tone.

The Author has applied this test to irons of almost every kind, and especially to those containing copper and arsenic, but the disturbing influence of these substances is but very small, and not always appreciable. The substantial accuracy of the method is shown in the following Table, in which the first column of numbers

gives the Author's determinations, while those in the second have been obtained by the ordinary method of analysis—oxidation of the sulphur, and precipitation as sulphate of baryta:—

	Colour Method.	Analysis.
	Per cent.	Per cent.
1. White charcoal pig-iron	0·005	0·005
3. Bar-iron containing 0·076 per cent. of arsenic .	0·007	0·008
7. Iron bloom	0·012	0·014
9. Mottled charcoal-iron	0·018	0·018
10. White pig-iron 0·071 per cent. arsenic	0·02	0·025
12. Malleable cast-iron	0·023	0·024
16. Cast-iron for ordnance with 1·55 per cent. copper	0·039	0·038
18. Open-hearth steel	0·05	0·047
21. " " "	0·10	0·093
22. Grey pig-iron	0·135	0·134
24. White pig-iron (Hörde) 1·88 per cent. P. . . .	0·21	0·19
25. Malleable cast-iron	0·35	0·34
26. White coke pig-iron	0·45	0·46
27. " " "	0·70	0·66

The Author recommends a somewhat larger size of apparatus having the test-disks 55 millimetres in diameter for use in works smelting with coke, where the substances examined contain 0·1 per cent. and above of sulphur. The apparatus, with prepared test-cloths and the standard scale of colours, may be obtained from F. O. Söderberg, of the School of Mines, Stockholm.

H. B.

A New Gas Glow-Lamp. By D. Coglievina, of Vienna.

(Gesundheits-Ingenieur, 1886, p. 155.)

Dr. Auer v. Welsbach has recently invented a new form of glow-lamp, which has attracted considerable notice. The Author points out that in the present state of the rivalry of common illuminating-gas with electricity on the one hand, and with water-gas on the other, this invention may be regarded as pointing the way to a friendly reconciliation between all the interests concerned. In the matter of softness and brilliancy the new lamp is in nowise inferior to the electric glow-lamp. In using this invention with common coal-gas, the consumption of gas is only about one-half the quantity required in an ordinary burner, while, where water-gas is available, this new lamp renders it possible to utilize it at once as an illuminant, without the need of any costly and complicated carburetting process.

The Author states that in order to form an opinion respecting the merits of this invention, it is necessary to consider its applicability from two different aspects, namely:—first, as a means of burning water-gas; and secondly, in use with common illuminating-gas. For both of these purposes the apparatus consists essentially of two parts:—(1) of a substance capable of being rendered incandescent; and (2) of a method of heating, which must be

adapted to raise this body to the necessary temperature, in order to yield the light. With respect to the radiant body it is the same for both gases, and consists of a woven meshwork, which is impregnated with a substance, the composition of which is a secret. The network is thereby rendered capable of maintaining a white heat when raised to the necessary temperature. The substance used by Dr. Auer differs from those employed by all previous inventors, who have selected more or less costly materials, the manipulation of which entailed various difficulties—such, for instance, as platinum, magnesia, &c.; whereas he employs a common network, which can be easily obtained at any time, and an equally readily procurable substance of mineral origin. If the prepared fabric should prove as durable as those hitherto employed, an important advance will have been achieved. To raise this substance to incandescence when using water-gas, the inventor employs only a common two-hole burner, as Fahnahjelm has also done with excellent results for some time past, and the relative merits of their lamps can only be ascertained when endurance, cost, and photometric effect are accurately known. The chief interest in this invention lies in its application when used with ordinary coal-gas. For this purpose Dr. Auer employs a Bunsen burner, fitted with a tap which accurately measures, in the act of turning it on, the proper relative volumes of air and gas. This latter fact constitutes in itself a distinct advance on former methods of using this description of burner. The Bunsen burner is, however, one ill suited to modern requirements, and has been surpassed by many later discoveries, as, for instance, those of Popp, Somzée, and notably that of Clamond. The Bunsen flame is so readily affected by draughts, and indeed by the least movement of the air, that it can only be used indoors where the atmosphere is perfectly still. To obviate this, Dr. Auer encloses his flame in a glass chimney of considerable height. Thus treated, however, the new lamp can only be regarded as an extremely sensitive Argand burner. In conclusion, the Author points out that the invention can only be fully realized in towns where a supply of water-gas is available, and he states that, in places where coal-gas only can be procured, the new lamp can be used with advantage only in a relatively small number of cases for domestic purposes.

G. R. R.

An Absolute Electrometer.[1] By E. Bichat and R. Blondlot.

(Comptes rendus de l'Académie des Sciences, vol. cii. 1886, p. 753.)

The Authors have constructed an electrometer founded on the attraction of two concentric cylinders, having the advantage of

[1] A practical realization of the instrument here described is given in a patent taken out by Sir William Thomson, No. 4617 of 1883, where Fig. 30 is a drawing of the instrument.—Sec. Inst. C.E.

simple construction and of giving continuous indications. An insulated cylinder A is connected to the source, the potential of which is to be measured. A cylinder B, the axis of which coincides with that of the first, is suspended by means of a bar to the pan of a balance, and, through the beam of this balance, is connected to earth. The cylinder B is partly immersed in a cylindrical vessel c, of a diameter slightly greater (partly inserted inside A), also communicating with earth. The cylinder A exerts on the cylinder B an upward force, and the two cylinders B and A constitute a condenser. The length of these cylinders being sufficiently great with relation to their diameters, the distribution is the same as if they were infinitely long. If R and r are the radii respectively of the cylinders A and B, V the potential of A, that of B being zero, and F the upward force of B, then it is shown that—

$$V^2 = 4 \, F \, L \frac{R}{r}.$$

If R and r are in centimetres, and F in dynes, V^2 is given in absolute units C. G. S. To measure F, weights are placed in the pan of the balance, until equilibrium is re-established. The value of these weights expressed in grams, multiplied by the number g, gives the force expressed in dynes. To deaden the oscillations of the beam there is, suspended in the place of the second pan of the balance, a large cardboard disk, arranged to rise and fall in a glass cylinder of slightly larger diameter; the friction of the air renders the apparatus nearly aperiodic. The force F being, within wide limits, independent of the position of the cylinder B, the instrument may be used without weights by simply observing the inclination of the beam, which may be effected by reflection from a mirror. When equilibrium is established, F is equal to a constant multiplied by the tangent of the angle of inclination. This constant is deter mined once for all by placing in the first pan a known weight, the electrometer being discharged, and observing the corresponding deflection.

P. H.

Spherical Absolute Electrometer. By — LIPPMANN.

(Comptes rendus de l'Académie des Sciences, vol. cii. 1886, p. 666.)

This instrument consists essentially of an insulated metallic sphere, raised to the potential V required to be known. This sphere is constructively divided into two hemispheres, movable relatively to each other, and repulsed with a force ($= f$) when the system is electrified. There exists between f and V the relation $f = \frac{1}{8} V^2$. To measure f one of the hemispheres is fixed; the other is suspended by a trifilar system (both hemispheres may be enclosed in a hollow sphere to obtain uniform electric distribution). When repulsion occurs, the movable hemisphere can become displaced

only parallel to itself, the three suspension-wires then making a small angle α with their first vertical position; α is measured by reflection from a mirror. If p be the weight of the moving hemisphere, $J = p \tan \alpha$; and $p \tan \alpha = \frac{1}{8} V^2$. It suffices to know p, which is invariable; as to the radius of the sphere, its value is immaterial. In the case of inclosure of the hemispheres in a concentric sphere, which is connected to earth, the formula becomes $\frac{1}{8} \frac{b^2}{(b-a)} V^2$, where a and b are the radii of the concentric spheres. In one instrument, as constructed, $a = 3 \cdot 9$ centimetres, $b = 4 \cdot 92$ centimetres, $p = 3 \cdot 322$ grams. A millimetre scale at 1 metre distance, therefore, gave for the deflection $d = 0 \cdot 00373 V^2$; if V is expressed in volts, $d = 0 \cdot 0000140 V^3$.

P. H.

On the Thermo-Electric Properties of some Substances.

By G. Chaperon.

(Comptes rendus de l'Académie des Sciences, vol. cii. 1886, p. 860.)

From the growing importance of thermo-electric generators, the Author has been led to study methodically a certain number of chemical compounds, especially chosen from those easily reproduced in active state. The couple in each case is that of the compound and silver; the shape of the compound is generally long and thin; the resistance with badly-conducting substances is therefore enormous.

Values of Electromotive Forces.

	From 20° to 120°. Volt.	From 20° to 400°. Volt.
Positive substances:		
Iodide of silver	0·115	0·192
Phosphide of zinc	0·107	0·362
Sulphide of tin	0·052	0·227
Crystallized galena (a)	0·034	,,
Thin layer of oxide of copper	0·03	,,
Arsenide of zinc	0·014	,,
Antimoniuret of zinc	0·018	,,
Negative substances:		
Sulphide of silver	0·091	0·108
Specular iron	0·063	0·25
Crystallized galena (b)	0·029	,,

For iodide-sulphide of silver the law of variation of electromotive force with temperature suffers a sharp change, and does not appear susceptible of representation by a continuous function.

P. H.

On the Variation produced by Elevation of Temperature in the Electromotive Force of Thermo-Electric Couples.

By H. Le Chatelier.

(Comptes rendus de l'Académie des Sciences, vol. cii. 1886, p. 819.)

Metallic couples have, according to the researches of Avenarius and Tait, an electromotive force increasing between 0° and 400°, and following a parabolic function of the absolute temperatures of the two junctions,

$$E = A(T_1 - T_0) + B(T_1^2 - T_0^1),$$

a formula that may be put, when one of the junctions is kept in melting ice, under the simple form $E = at + bt^2$; t, ordinary temperature of hot junction, a and b constants depending on the nature of the couples. No precise observations have been made above 400°, but the same law has been supposed applicable; this the Author has submitted to trial, as accuracy is of very great importance in the measurement of high temperatures by thermo-electric currents. The method of experiment is stated, and that the law of Avenarius and Tait continues true above 400° with an approximation equal to that obtained below, up to a certain temperature-limit, varying with the nature of the couple. Above this temperature-limit, the formula established for lower temperatures suddenly ceases to be applicable, and must be replaced by a second formula of the same kind, the coefficients only of which are different. This is so at least for experiments with couples of pure platinum—platinum-iridium. With other couples experiments are not numerous enough to afford decision with certainty.

P. H.

An Instrument for Measuring an Invariable Quantity of Electricity.

By Marcel Deprez.

(Comptes rendus de l'Académie des Sciences, vol. cii. 1886, p. 664.)

This instrument is intended to easily measure, under any conditions of temperature and pressure, the coulomb or unit quantity of electricity. It consists of a U-tube, the two branches of which are sealed before the lamp and terminated in glass bulbs, whose volume is much greater than that of the cylindrical parts. One of the bulbs, as well as the corresponding branch, is completely filled with water, acidulated with phosphoric acid; the second branch contains also a little of this liquid at its lower part, but in the greater part of its length it is filled with air at a determined pressure, as in the terminating bulb. The branch filled with liquid carries four platinum wires placed two and two, two

at the upper part of the bulb and two in the cylindrical part, a little below the lowest part of the bulb. If into the latter two a current is projected, the water is decomposed, and the resultant detonating mixture accumulates in the upper part of the bulb, whilst the liquid rises in the second branch and compresses the air therein. If care be taken to note the starting and stopping points of the liquid column in the second branch (which is graduated), all the elements are known that are required to determine the quantity of electricity expended to generate the detonating mixture, and no corrections are required. That the instrument may be used indefinitely requires re-formation of the water decomposed at each operation. This is effected by passing an electric spark across the wires in the upper part of the bulb containing the detonating mixture.

P. H.

On the Transformation of Heat into Electrical Energy, and the cost of the latter in the case of Galvanic and Thermo-batteries and Dynamo-machines. By WILHELM PEUKERT.

(Centralblatt für Elecktrotechnik, vol. viii. 1886, p. 94.)

In galvanic batteries the chemical combinations of the materials employed develop or absorb a given quantity of heat; if with the algebraical sum of this be compared the maximum obtainable from the electrical current in the external circuit, the Author finds that for a Daniell's element 47·7 per cent., and for a Bunsen element 59·1 per cent., are regainable as useful electrical energy.

In thermo-batteries where the heat may be considered as directly transformed into electrical energy, only 0·16 to 0·06 per cent. is regainable where gas is used as the heating agent, and 0·5 per cent. when coke is thus used, compared with the heat obtained from the combustion itself.

In dynamo-machines the figures are 3·2 and 5·85 per cent., when driven by steam- and gas-engines respectively.

If the cost of each method of production be calculated, the following are the values for 500 watts per hour:—

	Shillings.
Daniell's element	1·06
Bunsen "	1·51
Thermo-batteries, Rebeick's star form	5·65
" " " straight form	7·17
" " Clamond's, heated by gas	16·03
" " " " coal	0·42
Dynamo-machine, driven by steam-engine	0·10
" " " gas-engine	0·25

The data and authorities for the different assumptions required in the above calculations are detailed in the Paper.

F. J.

Determination of Coefficient of Self-Induction.
By — LEDEBOER.

(Comptes rendus de l'Académie des Sciences, vol. cii. 1886, p. 606.)

The Deprez-d'Arsonval aperiodic galvanometer is employed under the conditions where, by means detailed in a preceding communication, the instrument is on the point of becoming periodic. Under these conditions the sole difference is the introduction into the formula for the ballistic galvanometer of the factor e, the base of Napierian logarithms. The coefficient of self-induction can then be determined by Maxwell's method as applied by Lord Rayleigh.[1] The substitution of the aperiodic galvanometer for the periodic galvanometer renders the method very practical, and avoids the effects of presence of magnets or powerful currents, and all the inconveniences due to the persistence of movement of the galvanometer needle. The formula is $L = r \frac{T}{\pi} \frac{\delta}{a} e$.

When the resistance of the coil of which the coefficient is to be determined is small, the additional resistance r must be very small; in this case it is more advantageous to employ the direct formula:—

$$L = \frac{T}{\pi} \frac{i}{a} e \frac{\delta}{I} \left[(R' + l' + \underline{\underline{\delta}}) \frac{R'}{R} + \underline{\underline{\delta}} \right],$$

where $\frac{i}{a}$ is the constant of the galvanometer, whose resistance is $\underline{\underline{\delta}}$; R, R', l, l' the resistances of the four branches of the bridge; $\underline{\underline{R}}$ that of the coil of which the coefficient of self-induction is L, with $\frac{R}{R'} = \frac{l}{l'}$, the galvanometer being inserted between R and R', on the one side, and l and l' on the other.

P. H.

On the Theory of Dynamo-Electric Machines working as Motors.
By GIZA SZARVADY.

(Comptes rendus de l'Académie des Sciences, vol. cii. 1886, p. 749.)

The relation of unit tangential effort F developed by a machine to the value G of the magnetic-field, and to the limit (*extrémité*) I of the current circulating in the armature, is—

$$F = (L)\, G\, I \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where (L) represents a coefficient, taking into account the length of active wires, the angles under which these wires cut the lines of

[1] Proceedings of the Royal Society, No. 213, p. 116, 1881.

force, and the arm of the lever at the end of which the effort is measured. It is the equation of a hyperbolic paraboloid. For a given current effort, the intensity of the magnetic-field is connected to that of the current by an equilateral hyperbola having its vertex on the principal parabola situated in the plane G = I. Let there be laid down on the plane G I the parabola $F = (L) I^2$, a projection of the principal parabola. A given effort taken on the parabola laid down has the same abscissa as the summit of the corresponding hyperbola, which is thus determined. As there is a maximum for the value of the field, and a practicable limit to the current for a given machine, there is also a limit to the effort that can be developed. The Author substitutes for the value of I, considered as an independent variable, the value $\frac{E - e}{R}$ in (1), R being resistance, E electromotive force between the terminals, and e contrary electromotive force. R being a constant, the scale of the electromotive forces may be so chosen that the abscissas of the paraboloid represent the differences $(E - e)$. The curve that gives I then gives also $(E - e)$ in function of G. Two cases present themselves in practice, accordingly as I or E are supposed constant.

From consideration of the latter case the Author deduces: that for a given value of E, there exists a maximum quantity of current and a maximum effort not to be confounded with the practical limits; that for a given effort there exists a minimum value of magnetic-field. The contrary electromotive force increases with the field, following an equilateral hyperbola. The maximum velocity corresponds to maximum useful work and to the efficiency $\frac{1}{2}$. That, the maximum effort increasing, the vertex of the hyperbola is removed from the origin O, and the maximum efficiency corresponding to this effort diminishes and becomes nil for the maximum effort. It is therefore necessary in calculations for motors to arrange that the efforts in normal working may be very inferior to the theoretic maximum effort.

The Author so far has considered the magnetic-field as independent variable. This is the case with separately excited machines. For self-acting machines this unknown law is replaced by an experimental curve, such as a characteristic that represents G in function of I to a convenient scale. This characteristic being traced in the plane G I, it is taken for trace of a projectant cylinder that cuts off in the paraboloid of efforts a curve representing the working of the machine.

The Author considers the case of a compound-wound machine, and some apparently paradoxical results are explained by the aid of the diagrams obtained from the Author's consideration.

P. H.

Application of Electricity to Propulsion on Elevated Railroads.

By Frank J. Sprague.

(Electrician and Electrical Engineer, New York, vol. v., 1886, p. 44.)

One of the existing elevated railroads of New York, the Third Avenue line, which is about 8½ miles long, is here subjected to exhaustive investigation, as to the power developed by the steam-engines now employed; as to the impossibility of increasing by steam-traction the traffic, which during business hours is with the present stock pressed to its maximum capacity; and further as to the advantages of replacing the motive power by electrical propulsion both in the direction of increased carrying capacity and greater economy of working.

The permanent-way consists of 17 miles of single track laid on girders supported by iron columns spaced 43 feet apart; and as it was designed for the locomotives now in use, the weight of these cannot be increased with due allowance for the margin of safety; and it is only by materially increasing the speed between the stations, twenty-six in number, and decreasing the time required for starting and stopping, that the carrying capacity can under existing circumstances be improved, as lighter rolling-stock cannot be used with proper regard to economy and safety.

The application of electrical propulsion affords a ready means of increasing the traffic resulting from the following advantages which it possesses, as compared with steam-traction: each car can if required contain its own unit of propulsion, and thus the whole weight of the train is made effective in starting and stopping, the mean speed being thereby increased; the intervals between the trains can be diminished; and the vibration and wear and tear of rolling-stock is much reduced.

During the busy hours of the day sixty-three trains are in operation, and the total power developed in the motors at one time is 4,640 HP.; for an electrical system, as proposed by the Author, where the work given out in stopping and descending gradients is recovered and reapplied for driving the train, the total HP. required would be 2,715, or a gain of 41 per cent.; while the saving in expense would be 71 per cent.

The summary of the Author's calculations and conclusions may be tabulated as follows, as regards the working on this special line, and under the circumstances detailed in the Paper:—

	For Steam.	For Sprague Electric System.	
Average tractive power supplied per train .	73·6	43·1	HP.
Passenger capacity of each 80-ton train . .	151	344	
Weight of train for 344 passengers	92·6	80	tons.
Relative strain in any unit of permanent-way.	100	66	„
„ cost of coal	350	100	„

F. J.

Heating Railway Foot-warmers by Electricity.

By Louis Figuier.

(L'Année scientifique et industrielle 19me année, Paris, 1886, p. 121.)

Mr. Tomasi has introduced an improvement in the plan for heating foot-warmers for railway-carriages with acetate of soda,[1] by causing a current of electricity to pass through the liquid solution in such a way as to produce an increase of temperature, and so maintain the heat lost by radiation.

The current generated by a dynamo, driven from one of the axles of a luggage-van, is sent through a circuit which extends from one end of the train to the other, and from this main circuit the branch conductors, that pass through each foot-warmer in a longitudinal direction, are connected.

The foot-warmers, which are previously filled with acetate of soda, hyposulphite of soda, or some other salt of soda, having the property of maintaining a large amount of latent heat, which is disengaged when passing from a liquid into a crystalline state, are before starting plunged into boiling water, and when sufficiently heated, placed in the carriages, and connected with the circuit.

When the train is stopping no effect is produced, but as soon as a sufficient speed is attained the electric current, generated by the dynamo, traverses each foot-warmer, and the conductor in it being of less section than the one outside, a greater amount of resistance is offered to the passage of the current, and in consequence heat is produced, and is communicated to the solution, replacing that which has been lost by radiation in warming the vehicle. The quantity of latent heat in the solution being considerable, a stoppage of even three hours is not capable of producing such a cooling effect as to render necessary its being reheated by other means beyond that described; therefore, a train may travel from Calais to any part of Europe without there being any necessity to change the foot-warmers. It will readily be seen from this, the great advantage that such a system offers, both to railway companies and to passengers; in the first place fewer foot-warmers are required, and there is a saving in the cost of labour, maintenance, fuel, &c.; whilst, in the second, the comfort of the latter is at the same time increased.

A simple arrangement by which the conductor in the foot-warmer is thrown out of circuit, when too hot, prevents any danger from overheating.

P. L. N. F.

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[1] Minutes of Proceedings Inst. C.E. vol. lxi. p. 376.

Telemaregraphs. By J. Troost.

(Annales des Ponts et Chaussées, 6th series, vol. x. 1885, p. 763, 1 plate and 2 woodcuts.)

Fifteen stations have been fitted up for tidal observations along the Scheldt, between Ghent and Lillo, and along its tributaries, and connected with a central registering station by four telegraphic wires. Each station is provided with a tidal indicator and an observer. The tidal indicator has a pulley, which is turned by the movement of a counterpoised float suspended from a cord wound round the pulley. A pinion on the axle of the pulley works in a segmental ratchet, turning on another axle, and thus imparts to it the motion of the float. The ratchet sector carries a pointer, turning on the same axle, and whose extremity travels along a concentric scale, and indicates the position of the float above a given datum. Another smaller sector is fastened on the same axle, and its motion is accordingly proportional to the motion of the float. This sector is in contact with the observer, and by aid of this ingenious apparatus, which is fully described in the article, it is enabled to transmit an electric current to the central station during a period proportionate to the distance it has turned from its initial position. The duration of the current, and consequently the height of the tide at the given time, is recorded at the registering station by a graver marking a horizontal line along a zinc plate on a vertical revolving cylinder. The graver is pressed against the plate during the passage of the current; and consequently the length of the line graven on the plate is proportionate to the height of the tide at the time. The observations are transmitted at intervals of five or ten minutes; and the graver descends a slight distance after each record, so that a series of equidistant parallel lines are marked on the plate, forming the ordinates of the tidal curve for the particular station. The records of four stations are successively registered by one instrument on the same plate, the greatest length of any line being less than a quarter of the circumference of the recording cylinder. If the variations in level were considerably less, one registering instrument would suffice for several stations. Copies of the records are printed off from the zinc plates. The cost of these instruments was £1,576.

L. V. H.

On a Method for the Electrical Calibration of a Metal Wire. By Dr. M. Ascoli.

(Centralblatt für Elecktrotechnik, vol. viii. 1886, p. 67.)

The advantages of the method here described arise from the fact that no extra instruments are required besides the "bridge" of which the wire forms a part, and that the calibration can be effected on the wire *in sitû.*

The "bridge" is connected up in the usual way, as shown by a diagram; a wire, the resistance of which need not be determined, being joined up to form two of the branches of the "bridge," the other two being formed by the wire under calibration; a commutator is added by which a resistance R can be inserted at either end of the latter. The resistance of the wire contained between the two readings when balance is obtained, R being inserted first at one end and then at the other, will be equal to R; and as the ratio of the other branches can be altered at will, the length of the wire equal in resistance to R can be determined at any part of its length. If R then be taken small enough, the wire can be easily and accurately calibrated.

The Author recommends that a curve should be plotted with the "mean millimetre resistances" at each point as ordinate, and the position of that point as abscissa; the area contained between any two given ordinates will then give the resistance of the wire between the points to which they correspond. A full description of the best way of constructing such a curve, and illustrations from actual experiment, are given at some length.

F. J.

Balata and the Balata-Industry in Berbice. By G. S. JENMAN.

(*Timehri*, being the Journal of the Royal Agricultural and Commercial Society of British Guiana, December 1885.)

Balata is the juice of the bark of the Bullet tree—*Mimusops Balata* of the botanist—and resembles gutta-percha in some respects and india-rubber in others. The industry of Balata-collecting on the Canje River, and its creeks and tributaries, extends back only twenty-five years. The copious milk secretion in the bark of the Bullet tree has of course been always known, but that it might be turned to any economic use appears not to have been known before the year 1860, or thereabouts. In 1862 samples were sent to Messrs. Silver and Co., and to the Gutta-Percha Company of London, and in 1865 the quantity exported was 20,000 lbs.; but the trade fell off, and did not much revive until 1879, when the quantity exported was 47,483 lbs., of the value of £2,543 5*s.* 10*d.*, and in 1882 the quantity was 105,112 lbs., of the value of £5,849 3*s.* 10*d.* The present quoted price of Balata, in the English market, is 15*d.* per lb. The raw milk weighs rather more than 10 lbs. to the gallon, and loses rather less than half its weight in drying. A sample contained in 100 parts: Water, 39·04; Balata, 60·31; and mineral matter, 0·65. Dr. Hugo Muller, F.R.S., reported to Sir Joseph Hooker that he had obtained an opinion of it from an india-rubber manufacturer, which was to the effect that the manufacturers treated it as a superior kind of gutta-percha; but, on account of its high price, they used it only for superior purposes. Nevertheless, the report continued, Balata is distinctly different from gutta-percha; it is

somewhat softer at ordinary temperature, and not so rigid in the cold. The chemical composition, however, is probably identical with that of gutta-percha and caoutchouc. It is superior, also, in that when exposed to light and air it does not become brittle. The electric insulating quality of Balata is said to be quite equal to that of gutta-percha.

The Bullet tree reaches, at maturity, a height of 120 feet, with usually a large spreading head, and a trunk 60 or 70 feet long and 4 or 5 feet in diameter, and is almost the same size from a few feet above the ground to the first branch. The wood is of a reddish tinge, 80 lbs. to the cubic foot, durable for buildings, but is not used for piles in water, Greenheart being obtainable in this region. The largest of the Bullet-wood trees are not cut for timber, as it is too difficult to get the logs out by manual labour. They would square 3 feet 6 inches. The largest now cut square 2 feet 6 inches; the smallest size cut square 9 to 12 inches. Most of the grown-up trees seem to be from 1 foot to 2 feet in diameter; those with trunks 4 or 5 feet in diameter, which have large spreading heads lifted clear above the general forest, are only found here and there. The wood-cutters of this district work on the borders of the creeks which penetrate the forest. They go no more than two days' journey from the settlements for the Balata milk, and no more than 1 mile, or 2 miles, for timber. The present settlers are of pure negro descent, without Indian blood. They are the descendants of the freed slaves of former European settlers, and number about six hundred and twenty. The total population on the Canje River is, indeed, eight thousand three hundred and forty-six, but seven thousand seven hundred and twenty-six live near the mouth of the river, below the forest region, and are not regarded as the true river people, who inhabit the banks for 30 or 40 miles in the upper part of the river. The Canje falls into the estuary of the Berbice River, and is said to be one of the deepest rivers, though not the largest, between the Amazon and the Orinoco, and that it is navigable for vessels drawing 14 feet of water 100 miles from its mouth.

C. SL.

The Resin-Industry in the Landes. By A. RENARD.

(Bulletin de la Société d'Encouragement, vol. xi., p. 498.)

The Landes district embraces a tract of land about 3,460,000 acres in extent, which was formerly swampy, but has now been completely drained by numerous drainage canals. The soil is sandy, but a short distance below the surface is a hard layer which forms one of the greatest obstacles to the growth of trees. The pines were first planted to arrest the progress of the sand dunes on the coast; now the whole of this district is covered with forests. The *pinus maritimus* is the tree which predominates; its seed is sown broadcast, and every four or five years the plantations are

thinned by cutting down the weakest trees. In twenty-five or thirty years the trees are about 5 or 6 feet apart, and after this time any trees which may be removed are first tapped by making two large notches in them on opposite sides of the trunk. The resin which exudes is collected from time to time, and in four or five years the tree is cut down. The trees which are finally allowed to remain are 26 feet apart, and when their trunks attain a diameter of 12 to 14 inches, the collection of the resin commences. On the eastern side of the tree and near its foot incisions are made in April, and are renewed from time to time until a scar is produced 10 or 11 feet high. After about five years the same process is repeated on the south side of the tree, the original cut healing meanwhile. The trees do not suffer, and the tapping can be repeated on the tree for two hundred consecutive years.

The resin is collected by suspending a small pot beneath the cut in the tree by means of an iron spike. Every fortnight the resin is collected in vessels of about 10 gallons, which are then emptied into subterranean tanks containing 100 gallons. From the latter the barrels are filled. Another quality of resin is obtained in October by scraping off the solid crust adhering to the scars. This is usually kept separate, and is sold under the name of galipot.

The resin as obtained from the trees is the raw material for the manufacture of spirits of turpentine. The first operation is to heat the resin gently for twenty-four hours, when about 12 per cent. of water, together with earthy impurities, separates and falls to the bottom of the copper vessel. Chips of wood, leaves, &c., rise to the surface and are skimmed off. The clarified resin is run into copper retorts of a capacity of 66 gallons, which are heated by direct fire, the distillation of the turpentine being facilitated by the admission of a small quantity of water into the retort. The yield of turpentine varies from 15 to 18 per cent., the residue in the retort being solid resin or colophony. This resin is sometimes used for making resin oil by distilling at a dull-red heat. The yield of oil is about 80 per cent. The chief consumption of this oil is for lubricating, for which purpose it is mixed with mineral oil. It does not solidify when cooled, but has a tendency to clog or gum. Mixed with linseed oil it makes good printing ink. By distilling the resin rapidly a more consistent product results, which is mixed with slaked lime, and finds a ready sale as lubricating grease for carts, wagons, &c.

W. F. R.

The Production of Water-jets by means of Liquid Carbonic Acid.

By B. Fischer.

(Zeitschrift der Architekten Ingenieur-vereins zu Hannover, vol. xxxiii. 1886, p. 188.)

At the Rehburg baths water under the pressure of a column of 2·7 metres was used in the jet or rain-bath (*spritzbad*) which, according to the medical authority, was quite insufficient; as, to

realize the full efficiency of this method of treatment, the water-jets should issue under a pressure of at least two atmospheres, and the quantity of water for one application of one minute should be 40 litres. This corresponds to a velocity of efflux of 20 metres, and a discharging orifice of 6½ millimetres, or an equivalent area of 100 apertures of 0·65-millimetre diameter.

As both steam and hand-driven pumps were found to be too expensive, it was decided to obtain the necessary pressure from liquid carbonic acid, as it is now currently supplied in bottles containing 10 litres under a pressure of 40 atmospheres. The apparatus consists of an expansion-vessel 1 metre high and 430 millimetres in diameter, and a pressure-vessel 1 metre high and 380 millimetres in diameter, into which the water is admitted. The pressure-vessel is supplied with hot and cold water-pipes, discharge and blow-off pipes for the spent gas, a thermometer, two gauge-glasses, and two service pressure-pipes for baths. The expansion-vessel contains a pressure-gauge, cleaning hole, safety-valve, and the supply-pipe for the carbonic acid. The capacity is 140 litres, while that of the pressure-vessel is 110 litres. The working pressure required is 2½ atmospheres excess, or 3½ actual. The 10 litres of liquid acid weighing 8 kilograms while 1 cubic metre of the gas weighs 2 kilograms at the ordinary temperature or pressure, or 7 kilograms at 3½ atmospheres. The contents of the bottles, therefore, will expand to 1·143 cubic metre or 1,143 litres, which is sufficient for twenty-nine baths. As the volume of the gas in the expansion-vessel increases during the operation about 40 litres, the final pressure will be only 2·7 atmospheres, which is, however, of no particular disadvantage.

After each bath the pressure-vessel must be immediately refilled, otherwise there may be an escape of carbonic-acid gas into the bath-room.

The cost of the apparatus was about £50, and that of the acid 16*s*. per bottle, or about 6½*d*. for each bath. The arrangement is found to work well, being extremely simple and taking up only a very small space.

H. B.

New Method of Measuring the Heat of Combustion of Charcoal and Organic Compounds. By MESSRS. BERTHELOT and VIEILLE.

(Annales de Chimie et de Physique, 6th series, vol. vi. 1885, p. 546.)

The combustion of charcoal and of the different derivates of the carbon hydrates, is of special interest because of the part these play in gunpowder and in the explosive compounds of nitrogen.

The Authors have devised a calorimetric bomb in which any hydrocarbon whatever may be burnt with pure oxygen at constant volume in an extremely short interval of time. To fixed substances, perchlorate of potash is added, and the mixture burnt in an atmosphere of oxygen. It seems preferable to use pure

oxygen compressed to about 7 atmospheres, and a weight of combustible such that only 30 or 40 per cent. of the oxygen is used. The oxygen may be compressed even up to 25 atmospheres. The cylindrical bomb is made of platinum lined with iron and having a steel cover. A bomb of 250 cubic centimetres is placed in a calorimeter containing 550 cubic centimetres of water. The combustible substance is placed on a platinum leaf or foil and inflamed by electricity. The combustion is complete, as was verified by collecting the gaseous products, and absorbing the carbonic acid by potash, when the residue was found not to contain any combustible gas.

The heat of combustion at constant volume is obtained. The oxygen introduced was saturated with vapour of water, so that the water formed by combustion was in the liquid state. The mean of two determinations gives the heat of combustion at constant volume of 1 gram; for cellulose (cotton), 4,200 calories; for brown charcoal, 6,660 calories; black charcoal, 5,970; and for elder-wood charcoal, 6,105 calories.

The results show: 1st. That brown charcoal, employed in the manufacture of powder, contains an excess of energy when compared with its constituent elements carbon and hydrogen, supposing the oxygen combined as water.

2nd. This excess of energy is less for cellulose (cotton).

3rd. Charcoal, obtained by heating slowly and regularly—as in the parts near the centre of an elder-wood branch—had lost even more than its excess of energy. The Authors conclude that the energy given to powder by the charcoal it contains cannot be calculated by merely knowing the percentage composition of carbon, hydrogen, and oxygen in it. The nature of the combination of these elements in charcoal is very important, for the heat of combustion may vary as much as one-tenth of itself with compositions almost identical.

4th. Black charcoal, obtained under influence of higher temperatures, comes nearer the heat of combustion of pure carbon, the excess of energy being dissipated by the elevation of temperature and the duration of the heating, conformably to what is known of certain metallic oxides strongly calcined.

The method of burning charcoal therefore plays an essential part, and the energy of charcoal ought to be the object of special calorimetric experiments for each variety and process of manufacture.

W. R.

On the Rate of Propagation of Detonation in Solid and in Liquid Explosives. By MARCELLIN BERTHELOT.

(Annales de Chimie et de Physique, 6th series, vol. vi. 1885, pp. 556.)

The velocity of propagation of the reactions in explosive bodies is very different in ordinary combustion, as of gunpowder, to that of detonation proper to dynamite, gun-cotton, nitro-glycerine, and

other analogous substances. The discovery of the explosive wave by Mr. Vieille and the Author has thrown light on the extraordinary properties of these new explosives.

The following are the results of experiments, extending over several years, by the French Commission on Explosives, and they supplement those of Abel in 1874. In these dangerous experiments Colonel Sebert and Mr. Vieille took a prominent part. The substances operated upon included gun-cotton, dynamite, liquid nitro-glycerine, &c. The charges were compressed and exploded in tubes of lead, tin, and gun-metal. Most of the measurements were made with the velocimeter designed by Colonel Sebert, slightly modified to start the blackened plate by hand, and by the same movement to fire the charge automatically.

Conductors of very fine insulated wire were wound round the tubes every 25 metres of their length, and each of these carried an independent electric current acting on a little electro-magnet of the recording apparatus, which indicated on the blackened plate the breaking of the successive wires as the detonation travelled along the tube.

On the 27th of September, 1882, leaden tubes of 6-millimetres interior diameter, and 10-millimetres exterior diameter, were filled with nitro-glycerine. The passage of the explosive wave was recorded by the breaking of the fine copper wires carrying the current and wound on the tubes. The firing-plug, 1·5 gram of fulminate, was fixed in one end of the tube in contact with the nitro-glycerine. The speed was 1,024·3 metres per second.

On the 12th of June, 1884, in a tin tube of 4-millimetres diameter, charged with gun-cotton, the velocity of detonation was 6,184 metres per second. With gun-cotton pulverized and compressed in leaden tubes of 4-millimetres exterior diameter, and 100 metres long, the mean speed of propagation of the detonation was 5,200 metres per second. The same explosive more tightly charged in tin tubes of 4 millimetres gave the mean speed 5,916 metres per second; and for tubes 5·5 millimetres the speed was 6,100 metres per second; showing that the speed increases with the diameter of tube and density of charge, and is also more rapid in tin than in leaden tubes. Gun-cotton (fine grained) tightly charged in leaden tubes of 5·5-millimetres exterior, 3·15-millimetres interior diameter, and 34 metres long (the charge per metre being 9·7 grams), gave the mean speed 5,406 metres per second. Loosely charged in leaden tubes of 8·44-millimetres exterior and 3·77-millimetres interior diameter (the charge per metre being 11·15 grams), the mean speed obtained varied from 3,767 to 3,795 metres per second. Operating with dry compressed gun-cotton placed in continuous train in the open air, Abel found speeds from 5,320 to 6,080 metres per second, whilst gun-cotton in iron tubes, and separated by intervals of 1 metre, gave 1,800 metres per second, the fall in speed being due to the discontinuity.

The Author gives the results obtained with various other substances exploded in tin and in leaden tubes. Liquid nitro-glycerine

[illegible] The discovery of the explosive wave [illegible] the Author has thrown light on the extra- [illegible] of these new explosives.

[illegible] the results of experiments, extending over [illegible] French Commission on Explosives, and they [illegible] Abel in 1874. In these dangerous experiments [illegible] Vieille took a prominent part. The sub- [illegible] included gun-cotton, dynamite, liquid nitro- [illegible] were compressed and exploded in tubes [illegible] metal. Most of the measurements were [illegible] designed by Colonel Sebert, slightly [illegible] blackened plate by hand, and by the same [illegible] charge automatically.

[illegible] insulated wire were wound round the [illegible] of their length, and each of these carried an [illegible] current acting on a little electro-magnet of [illegible], which indicated on the blackened plate [illegible] successive wires as the detonation travelled

[illegible] 1882, leaden tubes of 6-millimetres in- [illegible] millimetres exterior diameter, were filled with [illegible] passage of the explosive wave was recorded [illegible] the copper wires carrying the current and [illegible] The firing-plug, 1·5 gram of fulminate, was [illegible] the tube in contact with the nitro-glycerine. [illegible] metres per second.

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[illegible] results obtained with various [illegible] [illegible] in leaden tubes. Liquid nitro-[illegible]

explodes with difficulty in narrow tubes and at low temperatures. Thus it did not detonate in leaden tubes of internal diameter less than 3 millimetres at 12° Centigrade, and the feeble detonation was only transmitted a short distance along tubes placed in the shade at 14° Centigrade; but when these tubes remained exposed to the sun, raising the temperature to 18° or 20° Centigrade, the detonation travelled the whole length of the tubes at the mean speed of 1,286 metres. With gun-metal tubes of 9-millimetres interior diameter the mean speed was 1,386 metres per second. Abel found the speed 1,672 metres under slightly different conditions.

Dynamite, in gun-metal tubes of 3-millimetres interior diameter, gives a mean speed of propagation of 2,668 metres per second. Temperature seemed to influence these results more than the variation of diameter. Abel has given 5,928 to 6,566 metres per second for dynamite cartridges 30 millimetres in diameter, placed end to end in continuous train in the open air. This great difference in the rate of propagation is doubtless due to the diameter of the explosive cylinder. Detonation is always propagated more quickly in dynamite than in nitro-glycerine, the former being more powerful in its effects in the open air, and the latter doing most damage when inside a solid mass.

The Author concludes from the experiments, chiefly on gun-cotton, that the speed increases with the density of charging, with the diameter (at least within the limit of the very narrow tubes used), and with the resistance of the envelope[1] (this being shattered in pieces by the explosion). Measurements made with a tube of 200-millimetres in length, bent and very sinuous, and another similar tube, being straight, gave sensibly the same velocity of propagation in both.

W. R.

On the Deformation of the Bore of a Gun in the region of the Obturator, and the Resistance of the Breech-Block.

By — Laurent, of the Société des forges et chantiers de la Méditerranée.

(Revue d'Artillerie, vol. xxvii. 1886, pp. 531, 550.)

In an article with the above title the Author considers these questions. Few authors have dealt with the subject, and the theories of General Gadolin, published in the Russian Journal of Artillery in 1868, and an article by Captain Duguet, published in the Revue d'Artillerie in 1877, are reviewed and criticised.

The first-named treated the subject fully, and recommended the employment of hoops with longitudinal locking, to counteract the tensile-strain exerted by the breech-screw on the interior wall of

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[1] The combustion or detonation is probably influenced by the nature of the metal in the tubes.—W. R.

its seating; he also considered the deformation of the bore around the obturator. The general confessed himself unable to completely solve the problem, in the presence of the difficulties of analysis which presented themselves, and moreover was obliged to rely on certain hypotheses which the Author considers to be contrary to the truth. Thus he admits that the strain, transmitted by the screw to its nut, is spread uniformly over its whole length, and that the pressure produced by the outer hoop in the longitudinal direction is entirely transmitted through the whole thickness of the metal above the seat of the screw. He shows, it is true, that in the nut the greatest strain takes place on the first thread, but the Author considers that the formulas given in the article are inaccurate, as he proceeds to show.

Captain Duguet, whilst taking accurately into account the conditions which occur in a piece submitted only to longitudinal strain, gives no results of calculation, and refers to the Russian article.

Considering, then, that the results up to the present time, as obtained by analysis, are very incomplete, no doubt from the difficulty experienced in the application of Lane's formulas, the Author, from recent researches, believes that he is in a position to treat the subject more accurately, and divides his study into three parts. (1) Is devoted to the establishment of new formulas. (2) Treats of the question of deformation of the bore. (3) The resistance of the breech-block.

Having established new formulas of displacement, the Author proceeds to apply them to the consideration of part 2, for which he takes the case of a hollow cylinder, submitted to internal pressure, and closed at the ends by two plugs independent of the cylinder. One plug is considered as the projectile, the other as the obturator, which may be a steel cup, or the De Bange form. In the former case the pressure acting on the inside walls of the cylinder tends to increase its diameter, and if the cylinder be indefinite, the walls would be expanded in a line parallel to themselves; but by reason of a portion of the cylinder being behind a certain point D situated at the obturator, which portion is not submitted to any internal pressure, the line of expansion near the obturator will not be parallel to the line of the wall of the cylinder, but curved from the point D to a point A on the parallel line of expansion.

The length of this curve will depend on the interior pressure P_1, the original radius r_o, and the expanded radius r'_o, which is a function of the thickness of the cylinder by reason of the external radius r_1 and the pressure P_2 exerted on its surface by the hooping. Consequently the deformation will be so much less for a determined pressure P_1, as r_o is less, r_1 greater, and P_2 still greater.

If the obturator were completely elastic, transmitting wholly the pressures in every direction, like liquids, over all its thickness, the curve of bending would have its origin at a point a little behind the obturator, but as it only transmits a portion of the

pressure, the point D is taken as in a line with the front face of the obturator.

In the case of the De Bange obturator the point D is changed, because the elasticity of the pads allows the better transmission of the pressure, and it is probable that D is behind the same point with the cup form of obturator; it is taken as at half-way up the pad. Applying these considerations to the case of a gun, where the obturator is not only a gas-check but is firmly attached to the breech-block, the Author gives a diagram showing the theoretical deformation of the breech-end, and applies the formulas of elasticity to the determination of the form of the curve produced in the bore by the pressure P_1, from which he deduces the argument that, if the breech of a gun be hooped only in front of the obturator, the tendency to deformation in the seating of the breech-screw would be reduced, as the pressure P_2 of the hoop would diminish the value of r_0. Other considerations compel hooping behind the obturator; so under these conditions, strictly speaking, a variable grip in the hoops, increasing in strength towards the section of the metal in front of the obturator should be given. The third part of the study is reserved by the Author for a future article.

J. H. R. W.

New Ordnance Material.

(Official Report to the U.S. War Department by W. H. Bixley, Capt. Engineers U.S. Army.)

After a personal visit to Europe in 1881–2, the Author submitted to the U.S. War Department a report that may be summarized under the following heads:—

Wire-Wound or Ribbon Guns.—The writer has treated the subject historically; and after noting the results of experiments with the 10·236-inch wire-wound gun constructed at the Armstrong works in 1881, has compared the new system with former systems, in regard to cost and effect, very much to the advantage of the wire system.

Gun-Carriages allowing no Recoil.—In an article, accompanied with diagrams and explanations, the Author briefly reviews Krupp's non-recoiling muzzle-pivoted guns, said by him to be the most successful non-recoil gun so far constructed. The advantages of this gun-casemate gun in its improved form are stated to be a greater superiority with respect to the complete protection of its cannoniers, and the rapidity and accuracy of its fire against a moving object. Several suggestions are made with a view of overcoming objections in the present construction.

Gruson's Non-Recoiling Minimum-Embrasure Gun Cupola Gun.—Following in the same line of construction as that described in Krupp's muzzle-pivoted guns, where the recoil is transmitted directly to the iron casemate without the intervention of any

hydraulic buffer, Mr. Gruson proposed later a non-recoiling gun-carriage which should be adaptable to his chilled-iron cupolas, their movable trunnion-bed carriages, and their minimum-embrasures. This mounting was patented by Mr. Gruson in 1883.

Gun-Carriages allowing but slight Recoil.—In 1881 Mr. Krupp proposed a slight-recoil trunnion-pivoted gun on a fixed centre-pintle carriage; but no guns and carriages have so far been constructed upon this system, except for the 3·2-inch guns for the armament of gun-boats.

Albini Carriage.—This form of mounting is due to Captain Albini, Italian Navy. It is at present manufactured in considerable numbers by both Krupp and Armstrong. The Krupp models are sometimes termed "link-carriages," and are generally for small guns. The Armstrong models are already in use in the British Navy for guns of 40-pounder, 4·7-inch, and 6-inch calibres.

Yoke-Mountings for 43-ton Guns on ordinary Carriages.—The Author had the opportunity of examining, at Shoeburyness in 1882, the new "Yoke" method of checking the recoil of long, heavy, breech-loading guns mounted on the ordinary forms of casemate carriages. The essential feature of this system, introduced by Col. Inglis, R.E., is the arrangement by which the recoil is transmitted from the gun to the casemate walls without using the chassis rails as an intermediary, thus relieving the rails and platform of all pressure except that of the weight of the gun and carriage, and allowing these to move to the rear smoothly and uniformly. It is proposed to use this mounting for all new heavy breech-loaders.

After noticing the front-parapet anchorage, tried at Shoeburyness in 1881, for controlling the recoil of heavy guns, the Author turns his attention to new muzzle-pivoting mechanisms. The constant endeavours on the part of most artillery officers to reduce the area of the embrasure through which heavy guns are fired, has led to the invention of several muzzle-pivoting carriages, such as: the Shaw carriage, tried at Shoeburyness with very fair results; the muzzle-pivoting, counterpoise gun-sling of Major King, U.S. Engineers, pivoted at the embrasure by means of a suspended chassis rail; the Krupp muzzle-pivoting, non-recoiling gun-casemate gun, pivoted both at the muzzle and at the embrasure by a ball-and-socket joint at the chase of the gun: the Gruson old model of minimum-embrasure carriage, in general principle similar to that of Col. Shaw; the Armstrong minimum-embrasure carriage (model of 1880); the Gruson minimum-embrasure carriage (C. 1880)—since 1875 the Russian Government have adopted this model for all small carriages. The Author has introduced several drawings into his descriptions, and has noticed other so-called muzzle-pivoting carriages that do not rightly come under this head.

Disappearing-gun Gun-carriages. — The disappearing carriages which seem to have so far met with the greatest favour in Europe are: the Moncrieff and King counterpoise carriages, the Moncrieff

hydro-pneumatic carriages, the Labrousse, Armstrong, and Razkazoff carriages, using either Belleville disk springs or hydraulic machinery, or both. In the first four of these carriages the force of recoil is utilized to return the gun to its firing position; in the last two the gun must be raised by the direct application of power from without.

English Official system of under-cover Loading.—After showing (by quotations from pages 181, 182, vol. vii., R. E. Professional Papers for 1882) what is being officially done in this direction in England, the Author proceeds to consider the Armstrong systems of under-cover loading. Most of these arrangements are the invention either of Sir W. Armstrong or of Mr. Rendel, and have been fully described by Captain Noble in a lecture before the Institution.[1]

New Forms of Projectiles.—The Author confines himself to discussing the new Palliser ribbed and jacketed chilled-iron projectiles, and the Gruson new chilled-steel projectiles. The cost of the chilled-steel projectiles is estimated at about twice that of chilled-iron projectiles.

New Explosives.—During the Author's visit to Magdeburg, he examined Gruson's new explosive of 1881 (Hellhoffite), which seems especially adapted to all military purposes, wherever a safe but violent explosive is required. It is more powerful than nitro-glycerine, safer than dynamite, cheap and easy to handle. Two other explosives, known as the "Miners' Powder" and "Ammonia-nitrate Powder," were also brought to the Author's notice.

In a few paragraphs on new methods of protection against moisture, the Author discusses the celluloid lining for ammunition cases, cork paint for exposed ironwork, cork composition for floors of magazines, the ventilation of magazines, and the Cohausen Psychroscope, and concludes with a report on modern armour materials—steel-faced wrought-iron, surface-hardened (or chilled) steel, and chilled (or surface-hardened) cast-iron. The Author's Reports are accompanied by numerous diagrams and important bibliographies relating to the subject.

C. C. L.

Report on the Bengal Earthquake of July 14th, 1885.

By C. S. Middlemiss, B.A.

(Records of the Geological Survey of India, vol. xviii. 1885, p. 4.)

The area over which this earthquake was felt may be roughly laid down as 230,400 square miles. Its external boundary was

[1] Heat in its Mechanical Applications. Heat-Action of Explosives. By Captain Andrew Noble. Session 1883–84, p. 201.

an irregular ellipse, within which was a similar figure of reduced area, over which the shock was felt with such considerable violence as to shake loose objects and to produce small cracks in double-storied houses. Finally another smaller figure could be drawn on the map, representing the district where destruction to buildings was greatest and loss of life has occurred. The Author made a survey of this district, and describes some of the effects of the shock, with reference in the first instance to the partial destruction of two chimneys at the jute works of Mr. Allister Macdonell, at Serajganj. These chimneys were respectively 135 feet and 95 feet in height, and were 338 feet apart in a direct line. The taller chimney lost 40 feet in height, and the smaller one 11 feet, which portions were shot away, a perceptible interval of time occurring between the fractures. Mr. Macdonell, who was an eye-witness of the destruction, from a position between the chimneys, asserts that there seemed to be a sudden thrust from below by which the upper part of the south chimney was first shattered and jerked off, and for some time a shower of bricks and mortar continued to fall round the base. A moment after the large chimney had gone, the factory chimney to the north was affected in a similar way. The Author points out that, according to Mallet, a wave of elastic compression travels through sand at the rate of 825 feet per second, and, assuming the rate to be the same through the mixture of sand and clay at Serajganj, the interval between the destruction of the chimneys would be about three-sevenths of a second, a period of time well above that which can be detected by the eye. The appearance of the ruins at the base is described by reference to diagrams. From the indications, he explains, it seems clear that the shock came from the direction south-east or south-south-east, and shot the bulk of the broken part of the chimneys over towards the north-west or north-north-west. Both in the cases of the cracks in the lower portion of these chimneys, and in those in some small Hindu temples at Sherpur, the Author was able to obtain evidence of the angle of emergence of the shock, which at Serajganj was about 60°, and at Sherpur varying from 45° to 55° and 60°.

Observations of a like character are recorded in connection with the destruction of a tomb at Jamalpur, and some gateway-arches at Muktigarchia. References are made to numerous examples, classed by the Author as of secondary importance, and a special section is devoted to exceptional phenomena, among which he enumerates earth-fissures and wells affected. In conclusion, the data afforded by the foregoing observations for the calculation of the seismic vertical, and the speed at which the earth-wave travelled, are exhaustively discussed.

G. R. R.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1885–86.—Part III.

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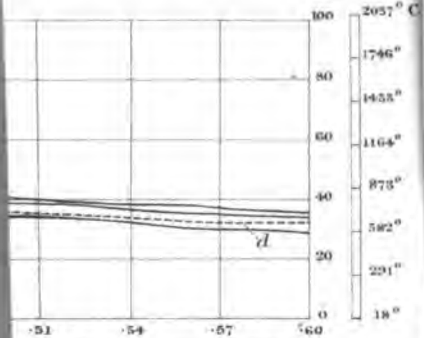

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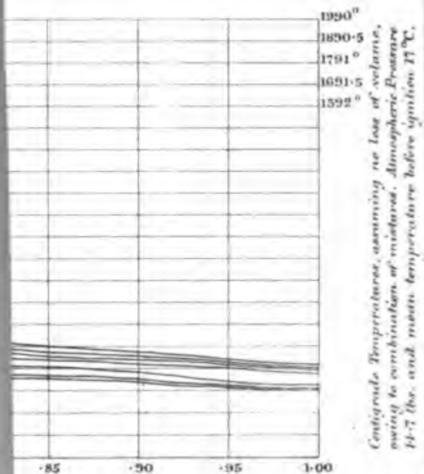

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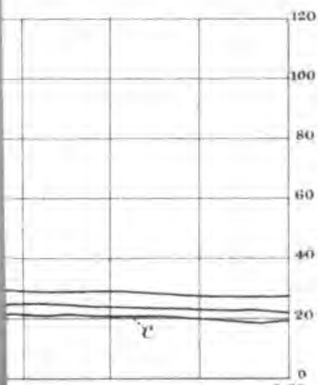

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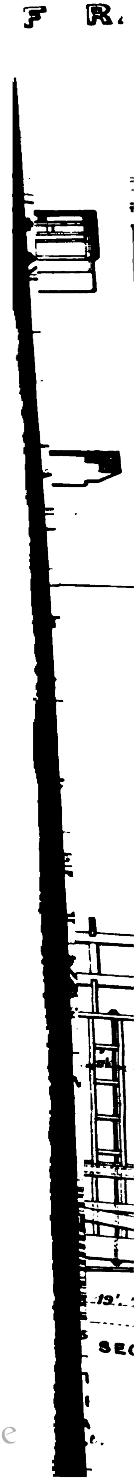

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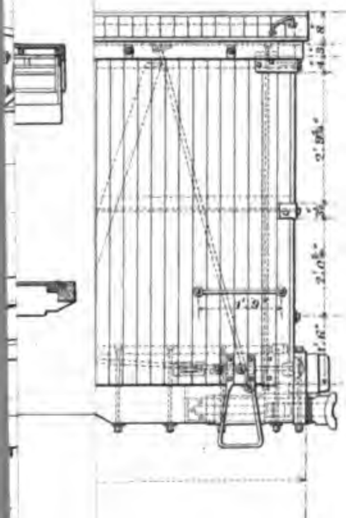

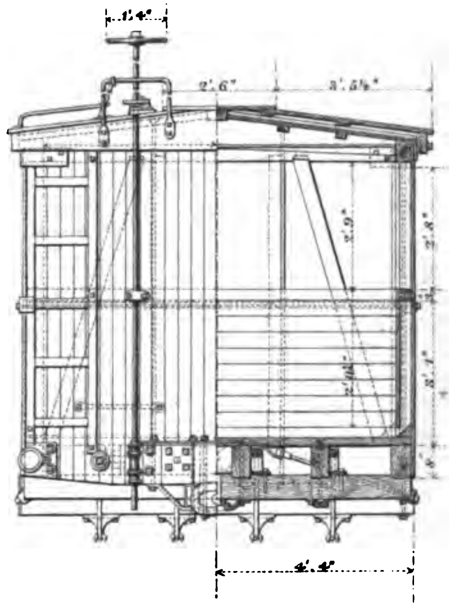

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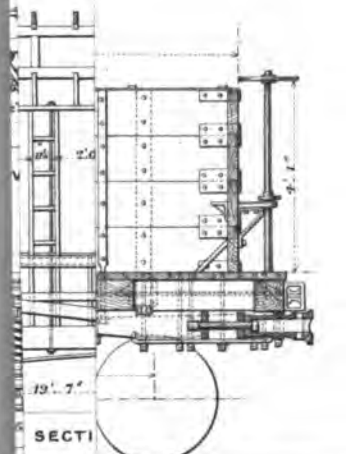

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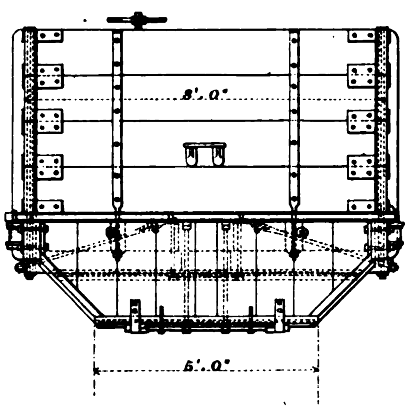

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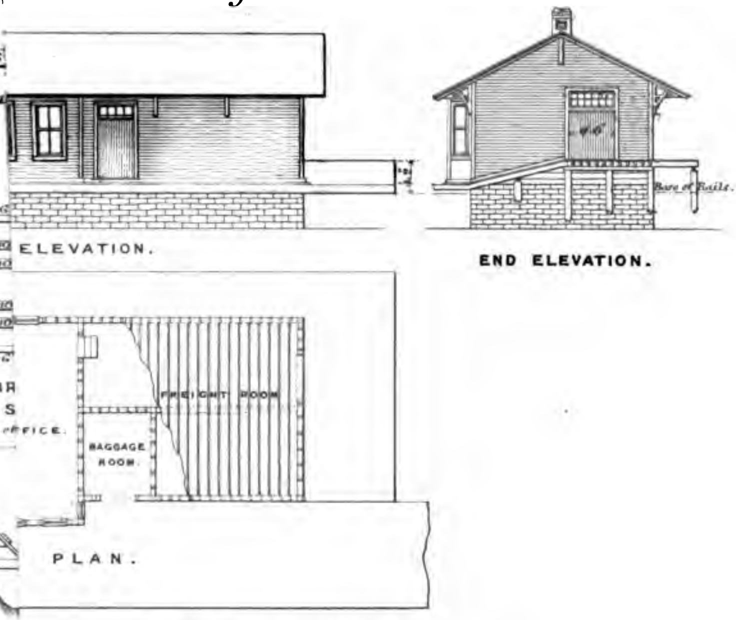

STATION BUILDINGS.

C.M. & St. P. Ry.

Scale of Feet.

Fig : 10.

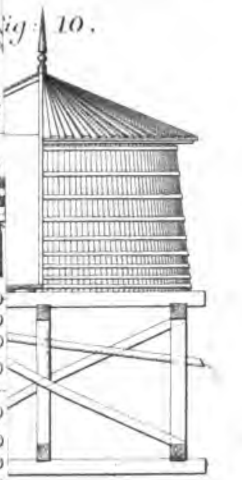

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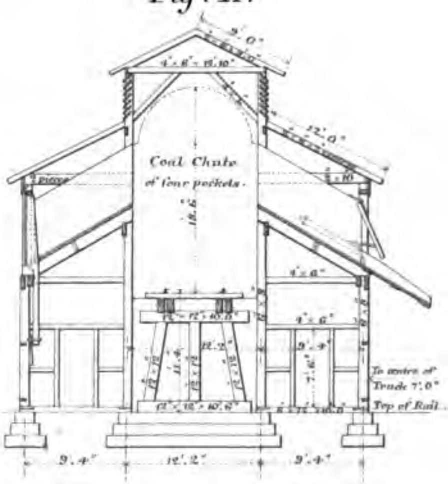
Fig : 11.

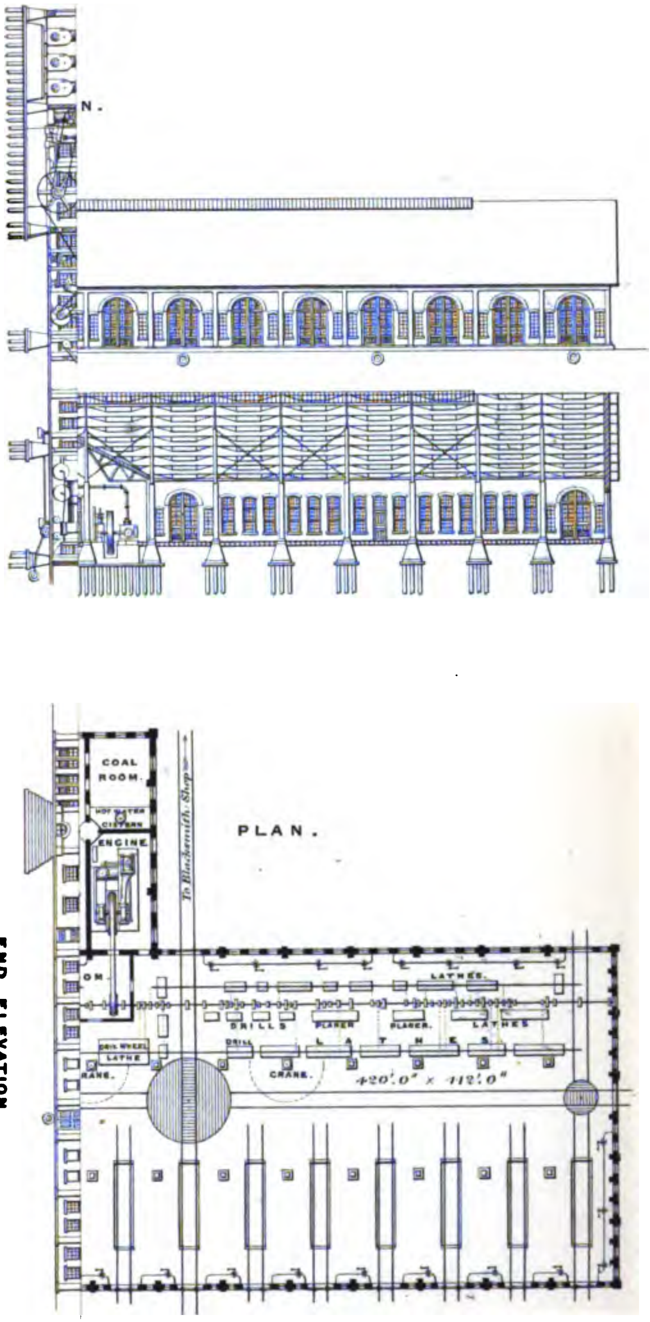


SECTION OF COAL CHUTE.

Scale of Feet.

THOS KELL & SON, LITH 40 KING ST COVENT GARDEN

PLATE. 4.



290 240 Feet.

THOS. KELL & SON, LITH. 40, KING ST. COVENT GARDEN

CANA
R


Summit Lake
Sink L.
Kicking Horse L.
N. Branch
Var. 24° 30
MAGN. NORTH
RIVER

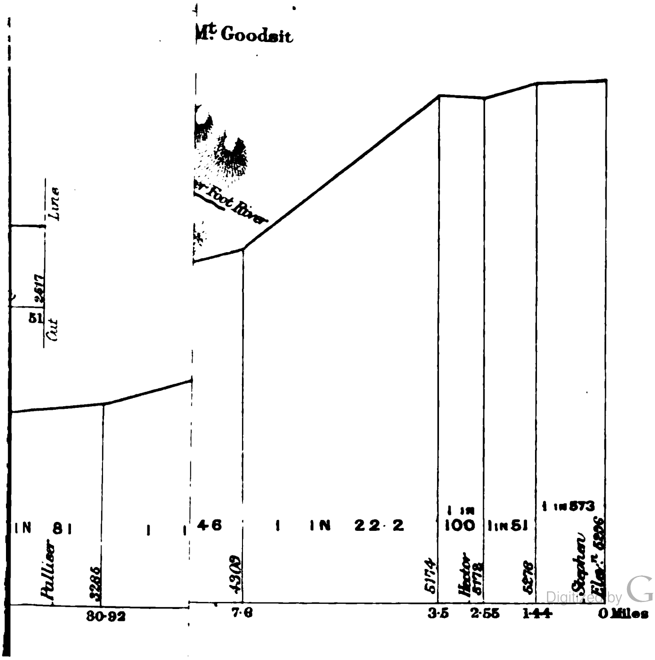
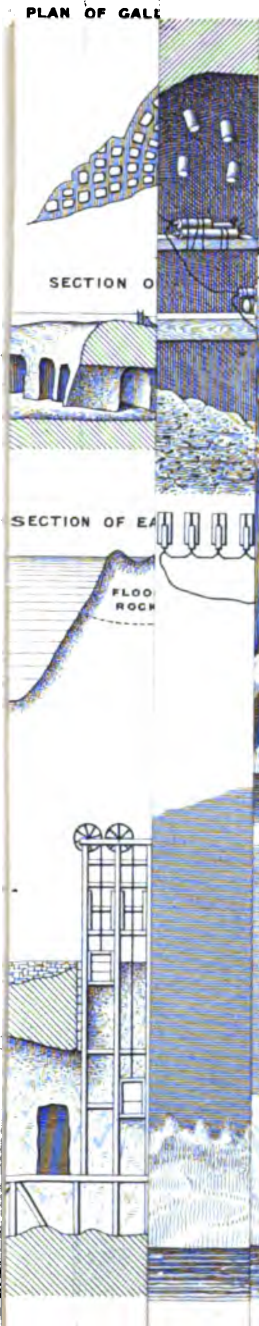

Mt. Goodsit
Foot River
Line
Cut
2517
51
IN 81
1 IN 46
1 IN 22·2
1 IN 100
1 IN 51
1 IN 573
Palliser
3286
4309
5174
Hector 5172
5276
Stephen Elev.n 5296
80·92
7·6
3·5
2·55
1·44
0 Miles

Fig : 2

HALLETT'S ES AND

PLAN OF GALL



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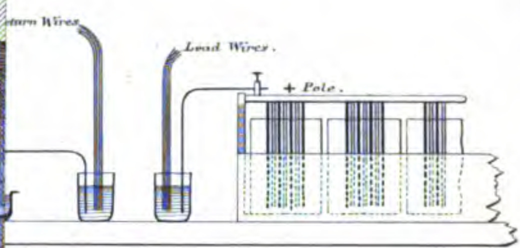


Fig : 14.

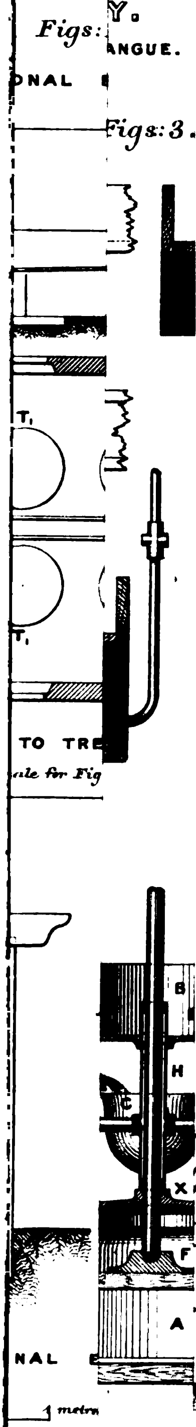
VIEW OF FLOOD ROCK EXPLOSION FROM BLACKWELL'S ISLAND.

Fig : 15.

VIEW OF FLOOD ROCK EXPLOSION FROM ASTORIA.

Session 1

THOS KELL & SON, LITH. 40, KING ST COVENT GARDEN.



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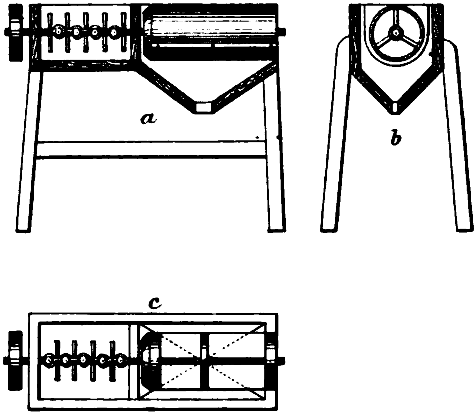

MIXING MACHINE.

Scale for Fig: 6. $\frac{1}{40}$.

1 2 metres.

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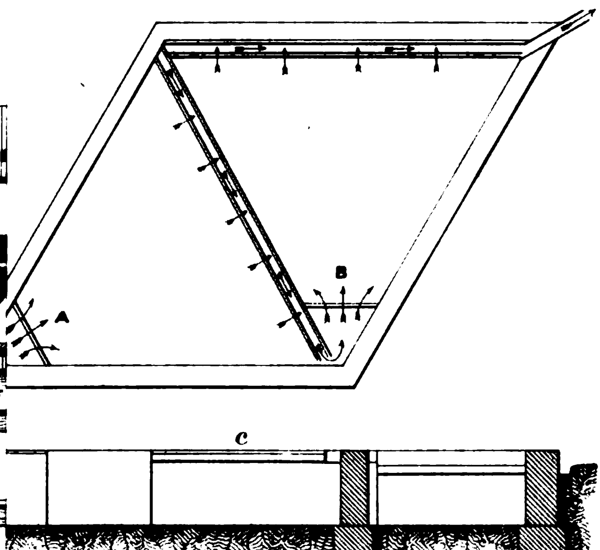
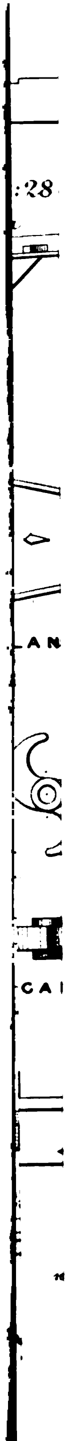
SLIME PITS.



THOS KELL & SON, LITH. 40 KING ST. COVENT GARDEN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